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MULTIPLE RESOURCE EVALUATION
OF REGION 2 U.S. FOREST SERVICE
LANDS UTILIZING LANDSAT MSS DATA

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16. Abstract

The overall objectives of this project involved the application of computer-aided analysis techniques using LANDSAT MSS data to the mapping and acreage tabulation of forest cover types for a 463,885 ha. USFS study area in SW Colorado, and to demonstrate the applications of manual image interpretation of LANDSAT MSS data to mapping geomorphic features. The vegetation classification evaluation is 84.4% at the generalized vegetation level and 79.8% at the community level. Topographic data were overlaid onto the vegetation classification to produce a multiple source data tape containing vegetation, elevation, slope aspect, and percent of slope. This results tape is on file at the USFS Computer Center to be used for day-to-day management needs. The flexibility to combine information in varied ways for problems having totally different interests and to produce 1:24,000 scale maps with tabular data for each combination increases the usefulness of the system. The computer cost for the combined vegetation classification-topographic data overlay was $0.012/ha. ($0.0049/acre), or $182.26/7½' USGS quadrangle. Standard products of LANDSAT MSS data were evaluated for the feasibility of mapping landslides, glacial deposits, bottomland features, drainage patterns, and for the USFS Land Systems Inventory. These products are being used in long-range and project level planning by the U.S. Forest Service.

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INTRODUCTION

The purpose of this LANDSAT-2 investigation was to implement direct applications of LANDSAT MSS data to land use planning in response to needs, concerns, and values as expressed by Region 2, U.S. Forest Service. All phases of the research involved cooperative efforts by members of a consortium: The Institute of Arctic and Alpine Research (INSTAAR), University of Colorado; The Laboratory for Applications of Remote Sensing (LARS), Purdue University; and Region 2, U.S. Forest Service with the participating San Juan National Forest, Rio Grande National Forest, and Carson National Forest (Region 3). Based on defined requirements for integrated long-range planning and immediate management concerns the results of this study have 1) applied computer-aided analysis techniques to LANDSAT MSS data for identifying, classifying, and mapping vegetative cover types, 2) employed manual image interpretation of LANDSAT MSS data for geomorphic mapping, 3) established a digital registration of topographic data with a vegetation classification derived from LANDSAT MSS data for a flexible overlay-recall system which combines features of interest to the user, 4) demonstrated quasi-operational applications of LANDSAT MSS data with ancillary data sets to land use planning and resource management, and 5) derived a cost/effective evaluation of LANDSAT MSS data for such applications.

The cooperation and interaction of members of the consortium has effected technology transfer to direct applications of LANDSAT MSS data. Significant steps have been taken to put the results of the study in a format useful to the resource planners and managers. As the study progressed, the U.S. Forest Service formulated many ideas which extended the activities beyond the proposed scope of the project. The original objective was to apply LANDSAT MSS data analysis to the U.S. Forest Service long-range planning process. However, the detail and flexibility of the resource information derived from this study has provided a data base for day-to-day management.

BACKGROUND

During the past 10 years, research involving multispectral scanner

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data and computer-aided analysis techniques (CAAT) has clearly shown the potential for such a combination of data and analysis techniques. Studies involving both aircraft and satellite MSS data obtained in 12 or more wavelength bands throughout the optical portion of the spectrum have indicated the value of the various wavelengths and wavelength regions for correctly identifying many earth surface features. With the advent of LANDSAT, the value of the synoptic view and repetitive coverage that can be obtained from satellite altitudes was clearly shown.

Research carried out as part of a LANDSAT-1 project (NASA contract NAS5-21880) and later on a SKYLAB project (NASA contract NAS9-13380) have indicated that in areas of rugged mountainous terrain forest cover types can be mapped and acreage tabulations obtained with a reasonable degree of success using satellite data and computer-aided analysis techniques. Both of these LANDSAT-1 and SKYLAB projects were carried out as cooperative activities between the Laboratory for Applications of Remote Sensing (LARS), Purdue University, and the Institute of Arctic and Alpine Research (INSTAAR), University of Colorado. LARS was responsible for the analysis of the satellite multispectral scanner (MSS) data while INSTAAR obtained the required field data for classification and evaluation, and interfaced with various user agencies involved in resource management activities in the test site areas. As a result of some of this work, a strong interest developed in applying the computer-aided analysis techniques to LANDSAT data in order to generate cover type maps of value to the U.S. Forest Service for land use planning activities. Therefore, this project was a logical extension of the work started under the LANDSAT-1 and SKYLAB programs.

The multiple use division of Region 2, U.S. Forest Service, identified the Southern San Juan Mountains Planning Unit as having a major role in the development of the planning process. The principal components used to categorize the area are vegetation and landform features. By combining vegetation and landform features the planning unit is subdivided into Ecological Land Units. These are the base combinations of resource data which form the foundation of the approach to the planning process being used in the Southern San Juan Mountains Planning Unit.

OBJECTIVES

The overall objectives of this project involved the application of computer-aided analysis techniques using LANDSAT MSS data to the mapping and acreage tabulations of forest cover types within the Southern San Juan Mountains Planning Unit, and to demonstrate the application of manual image interpretation of LANDSAT MSS data to mapping geomorphic features of the planning unit. The specific activities included 1) computer-aided analysis of LANDSAT MSS data to obtain an optimum cover type map for the study area, which included portions of the San Juan, Rio Grande, and Carson National Forests, 2) further development of effective and efficient computer-aided analysis techniques to improve the mapping of forest cover types in regions of rugged mountainous terrain, 3) development of a multiple source data tape containing topographic data (elevation, slope steepness, and slope aspect) and LANDSAT MSS classification results, and the development of computer programs to utilize the multiple-source data tape to produce digital overlay combinations, 4) generation of map and tabular data products from various combinations of LANDSAT MSS classification results with topographic data which were requested by the U.S. Forest Service personnel, 5) manual image interpretation of LANDSAT MSS data for geomorphic features using standard black/white transparencies and diazo film combinations of positive and negative transparencies, 6) close interaction of INSTAAR-LARS-USFS personnel to establish quasi-operational applications of LANDSAT MSS data to the planning and management objectives of the Forest Service by sessions and frequent workshops, and 7) derivation of a cost/effective evaluation of LANDSAT MSS data capabilities in assisting in broad area analysis.

PROJECT SUMMARY

Significant results were achieved during the course of this project in a number of areas. The integration of user needs with research capabilities gave specific direction to the investigation. An overview which summarizes the various phases of activity and results is presented here.

Vegetation Classification and Evaluation

The additional refinement of the modified cluster technique, which had been originally developed in a prototype form during the LANDSAT-1 and SKYLAB projects, has clearly indicated the value of this analysis approach for effective mapping of forest cover types in areas of rugged mountainous terrain. A considerable amount of time was necessary to define appropriate cover type categories of vegetation to be included in the classification. Support data for the classification and evaluation processes were acquired through extensive field work and interpretation of color infrared aerial photography obtained by NASA's WB-57 aircraft.

A comparison of three methods for test field selection indicated that the evaluation of the vegetation classification of LANDSAT MSS data did not vary significantly among the methods. These methods of test field selection were based on field data, a systematic grid of 2 X 2 pixels using photointerpretation, or proportionate homogeneous areas using photointerpretation. The definitions and descriptions of cover types which guide the spectral class groupings for cover types directly influenced the evaluation results. Cover types were defined and interpreted in three ways: narrow (restrictive), moderate (logical), and broad (extensive). The moderate interpretation paralleled the U.S. Forest Service descriptions and was used in the evaluation. The evaluation based on the number of correctly classified pixels out of a total of possible number of pixels was 84.4% at the generalized vegetation level and 79.8% at the community level.

Results of the vegetation classification derived from LANDSAT MSS data definitively illustrate that the same spectral classes in different geographic locations correspond to totally different cover types (informational classes). That is, the same spectral response may be obtained from different categories of cover types located in different geographic areas. In this particular study area of mountainous terrain the informational classes associated with some spectral classes changed from one 7 1/2' U.S.G.S. quadrangle to the adjacent quadrangle. This clearly indicates a need for further work in spectral stratification. The results of this study demonstrated that emphasis should be placed

on the development of more effective techniques for relating spectral response patterns obtainable from LANDSAT data to the informational classes as defined from ground truth data.

Topographic Data Utilization

Previous work at LARS developed a technique for overlaying topographic and multispectral scanner data. However, only preliminary steps had been taken in developing effective means of utilizing such a combined data set. Significant advances were made during this project to derive a multiple source data tape containing topographic data and classification results of MSS data. The format was designed to be more suitable to meeting user needs. The multiple source data tape includes the vegetation classification of 25 spectral classes, elevation in 100 m increments, slope aspect in 12 categories, and percent of slope in 8 categories. Additional data sets, such as soils or land ownership, may be added later by the U.S. Forest Service. The ability to generate in line printer output (scale 1:24,000) combinations of classification results and topographic data as selected by the various resource managers has been viewed as a valuable planning tool for the U.S. Forest Service. The selected combinations contain only the information of interest and value to address a particular problem. The flexibility to recombine the information in varied ways for problems having totally different interests increases the usefulness of the system. The data can be summarized in tabular format for area and percentage for each combination. This represents a major step forward in utilizing remote sensing technology coupled with ancillary data sets to meet needs of the user community and to obtain products of value to various resource management agencies.

Geomorphic Mapping

LANDSAT MSS data was evaluated for landform mapping in general and within the system used by the U.S. Forest Service. This resulted in the development of manual analysis techniques applicable to current planning efforts.

The initial work emphasized the U.S. Forest Service classification of the Land Systems Inventory and focused on the landtype association level and the landtype level, the level of next greater detail. The landtype mapping categories would provide a data base for some land use decisions which could not be made with the landtype associations. Categories at the landtype level for the study area were defined (not previously done by the U.S. Forest Service) and were mapped using low-level aerial photographs. LANDSAT MSS images were then evaluated as a mapping tool for both landtypes and landtype associations.

Because of the limitations of the landtype and landtype associations, additional evaluation of LANDSAT MSS data focused on the use of images as a tool for geomorphic studies in general. Features analyzed during this phase of the project often relate to specific aspects of the Land Systems Inventory but were not restricted to the confines of the system itself. Although methods were developed and evaluated using specific geomorphic features, these techniques can be readily applied by U.S. Forest Service personnel to other fields of interest within the planning structure.

LANDSAT MSS data were evaluated for the feasibility for mapping the following geomorphic features: 1) landslides, 2) glacial deposits, 3) bottomland features including floodplains and alluvial fans, and 4) drainage patterns as an indicator of the underlying geology and for possible hydrologic inventories. Standard products rather than computer enhanced products were emphasized because they are readily available, inexpensive, and more versatile for manual interpretations. The methods employed and analyzed include stereo modeling, snow enhancement, stereo reversal, seasonal combinations, and diazo color composites.

Cost Effective Analysis

The computer costs ($250.00/hr.), excluding personnel salaries and wages, for the vegetation analysis of LANDSAT MSS data and the topographic data overlay were $0.012/hectare ($0.0049/acre). Coverting this figure, the computer cost to derive the data base for one 7 1/2' U.S.G.S. quadrangle was $182.29. The computer time includes pre-processing and geo-

metric correction, development of training statistics, classification, evaluation, topographic data registration to the LANDSAT MSS data, slope and aspect calculations, and merge run plus ten combinations.

The overall cost analysis for the final products derived for the Southern San Juan Mountains Planning Unit was $17,907.00 (463,885 hectares or 1,148,230 acres). This includes the cost of computer time, materials, and personnel salaries and wages ($5.00/hr.; annual salary $10,400.00 without overhead) for the vegetation classification from LANDSAT MSS data, topographic data overlay, and geomorphic mapping. A necessary inclusion is personnel time for field work (vegetation and geomorphology), and data preparation for training statistics, spectral class descriptions, and evaluation. A per unit cost was $0.0386/ hectare ($0.0156/acre), or $577.65 for one 7 1/2' U.S.G.S. quadrangle. If the size of the study area was significantly increased, the unit cost would be less; if the size of the study was significantly decreased, the unit cost would be greater.

DESCRIPTION OF STUDY AREA .

J.P. Spencer, INSTAAR.   M.D. Fleming, LARS
C.L. Ernst, INSTAAR

The study area is centered on the U.S. Forest Service's Southern
San Juan Mountains Planning Unit. This is located in south-central
Colorado and north-central New Mexico. The planning unit is 283,500
hectares (700,000 acres) of mixed federal, state, and private lands,
and is on all/or portions of thirty one 7½'quadranges. This study area
lies at approximately 106° 7'30'' W - 107° 0°0° W longitude; 36° 52'30''
N - 37° 22'30'' N latitude. The center of the planning unit is 320
kilometers (200 airline miles) southwest of Denver, Colorado and 240
kilometers (150 airline miles) north of Albuquerque, New Mexico. There
are no major population centers in the study area. Fifty percent of
the planning unit lies in the Rio Grande National Forest, 35 percent in
the San Juan National Forest, and 10 percent in the Carson National
forest. The location of the planning unit is shown in Figure A.1.

An abundance of diverse landscapes with a variety of landforms and
vegetation types are found within the planning unit. The elevation ranges
from 2,400 meters (8,000 feet) to 4,000 meters (13,000 feet). Three
phases of geologic activity have occurred in the area during the last
135 million years. From 70 to 135 million years B.P. (Before Present), the
first phase, sandstones and shales were deposited on the floor of a shallow
sea covering the present southern San Juan Mountains. In the second phase,
the Tertiary, 3 to 70 million years B.P., the entire San Juan Mountain
Range was uplifted. There were repeated outpourings of lava and ash from
volcanoes in the region. These igneous materials cover most of the study
area today. During the last geologic phase the Tertiary volcanics were
modified by extensive valley glaciation. The area has numerous landslides,
avalanches, rock glaciers and glacial lakes.

The study area spans the Continental Divide. Major drainages west .
of the Divide include the Rio Blanco; Rito Blanco; East Fork of the San

39°45'N
108°W

● Denver

Colorado

SAN JUAN
NATIONAL
FOREST

RIO
GRANDE
NATIONAL
FOREST

● Monte Vista

Southern
San Juan Mountains
Planning Unit

37°N
109°2'30"W

● Durango

New
Mexico

CARSON
NATIONAL
FOREST

● Taos

N

0   40   80   120km

● Albuquerque
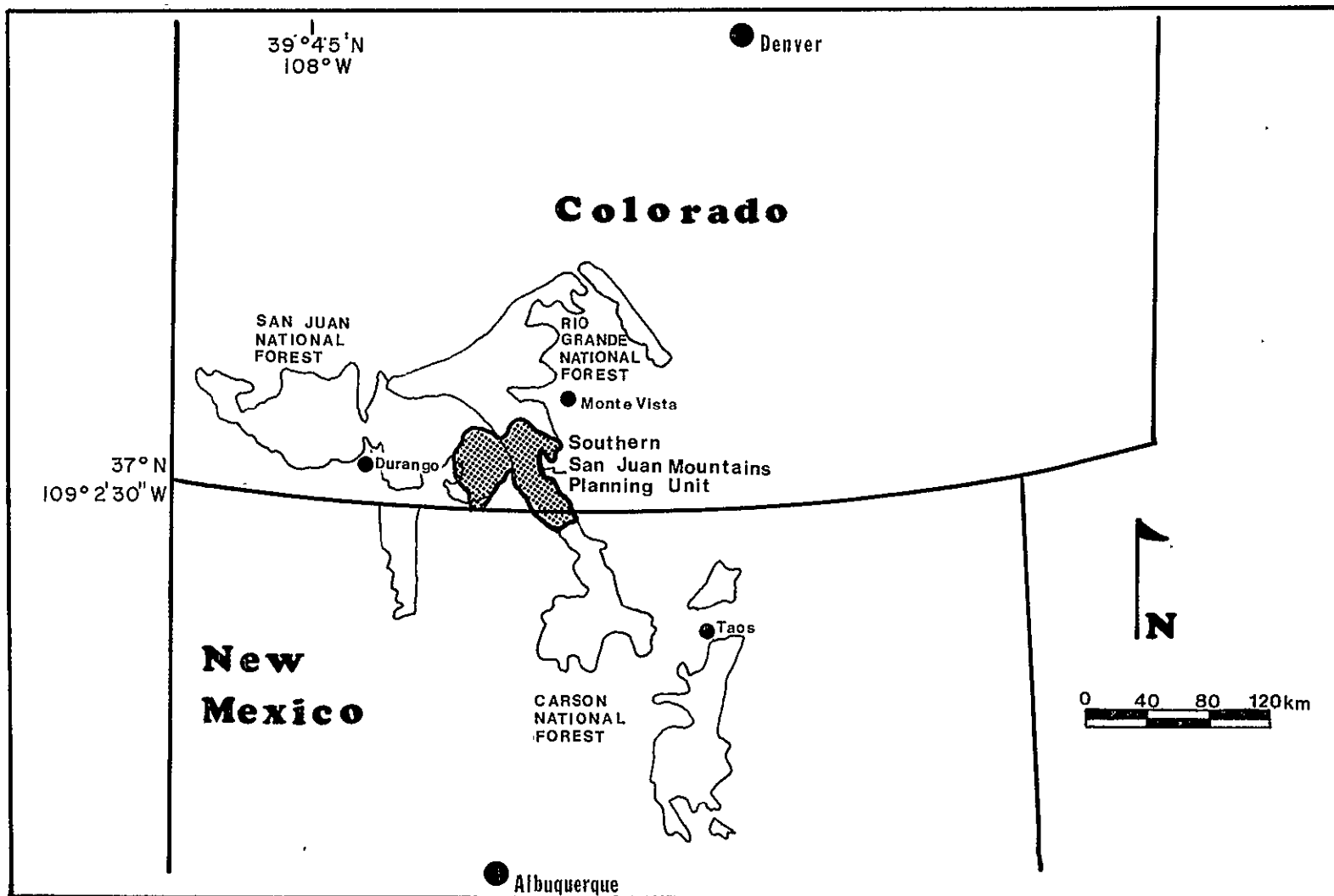
Figure A.1.   Location of Planning Unit. The Southern San Juan Mountains Planning
Unit is located in southwestern Colorado and north-central New Mexico.
The Planning Unit extends through parts of the San Juan and Rio Grande
National Forests of Colorado and the Carson National Forest of New Mexico.

Juan, Little Navajo, and Navajo rivers. East of the Continental Divide, the major drainages are the Alamosa, Conejos, and LaJara rivers, and the Rio Chama and Rio de Los Pinos.

The climate of the southern San Juan Mountains is typical of the Colorado Rockies. Low relative humidity, abundant sunshine, cool summers with frequent showers, heavy winter snows and wide daily temperature fluctuations are normal. The annual precipitation varies with elevation and ranges from 30.5 to 127.0 cm (12-50 inches) per year. More than half of the precipitation falls during the winter months.

Major forest tree species include Engelmann spruce (Picea engelmannii, Parry), subalpine fir (Abies lasiocarpa, Hook.), Douglas fir (Pseudotsuga menziesii, Franco), white fir (Abies concolor, Gordon), Ponderosa pine (Pinus ponderosa, Dougl.), aspen (Populus tremuloides, Michx.), oak (Quercus gambellii, Nott.), piñon pine (Pinus edulis, Engelm.), and juniper (Juniperus scopulorum, Sarg.). The scientific epithets follow Weber (1972).

In general, the vegetative cover is determined by complex interactions of edaphic, topographic, and climatic factors. The result of this interaction is a distinct distribution of vegetative cover types within various altitudinal ranges, Fig. A.2. Slope aspect and slope steepness influence microclimatic conditions which also have distinct effects on the vegetation. As elevation increases, air temperatures decrease but annual precipitation, cloud cover, and insolation intensity increase. An understanding of these interactions provides meaningful information to use in effective management of the forest resources.

The Southern San Juan Mountains Planning Unit is recognized for its scenic beauty. Glacial activity is evident in the heavily scoured river drainages. At higher elevations steep escarpments, rugged peaks, and rock outcrops are common. The landforms, the variety of vegetation, and the many streams and lakes make a visual impact on the visitors to the area. The planning unit offers many recreational opportunities, such as backpacking in the wilderness, camping in developed campgrounds, and hunting and fishing. The area has thirteen U.S. Forest Service campgrounds, and nine lodges with rental cabins. There are approximately 450 kilometers (275 miles) of trout streams, three major reservoirs, and numerous high lakes. The majority of the better fishing streams

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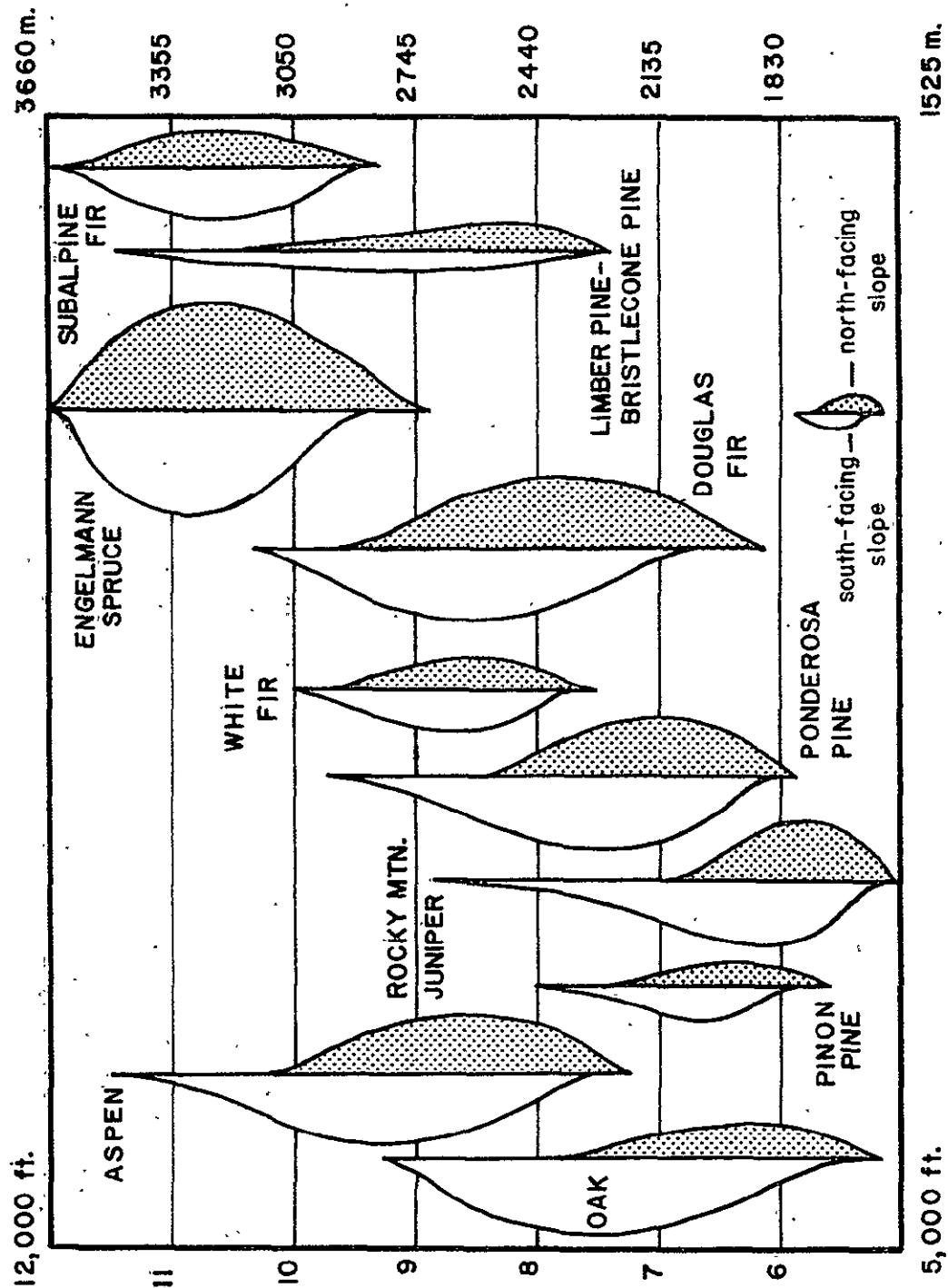
Figure A.2. Distribution of dominant tree species along an elevation gradient. The relative abundance is shown with respect to north- and south-facing slopes.

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are accessible by car. Many of the higher lakes can be reached by foot or on horses.

The planning unit provides habitats for a variety of wildlife. Elk and deer graze in the high country during the summer and move down into the valleys for the winter. Black bear range throughout the planning unit feeding on tuberous roots, grasses, small rodents, and insects. Antelope are found in the eastern Rio Grande portion of the planning unit. Insects, small birds and rodents such as mice, shrews, squirrels, chipmunks, beaver, muskrats, rabbits, white-tailed ptarmigan, and blue grouse feed on the vegetation, and in turn are preyed on by carnivores. Predators include the prairie falcon, red-tailed hawk, great horned owl, coyote, and bob cat, as well as bald and golden eagles. One pair of the endangered peregrin falcon is nesting along the Conejos River. The U.S. Forest Service is responsible for the management of the wildlife in the planning unit. While this does not involve setting of hunting seasons and bag limits, the U.S. Forest Service must manage the habitats which provide food and shelter for the various wildlife populations which use the planning unit for all or part of the year.

The U.S. Forest Service is evaluating potential ski area opportunities in the planning unit. One of these sites, on the East Fork of the San Juan River, is being immediately considered. This proposed ski area covers approximately 4,000 hectares (10,000 acres). Detailed studies of climate, landforms, vegetation, and other environmental features are being completed.

The wilderness potential of 87,300 hectares (215,650 acres) are currently being studied for designation as Wilderness Areas as required by the Wilderness Act of 1964. These are V-Rock, Blanco River Divide, Sand Creek, Chama-South San Juan, and Cruces Basin. Portions of the Conejos River in the Rio Grande National Forest are being evaluated for inclusion in the National Wild and Scenic Rivers system. Wild and scenic rivers are protected in their free-flowing state by federal law for their "outstandingly remarkable scenic, recreational, geologic, fish and wildlife, historic, cultural, or other similar values."

Forested areas cover 140,000 hectares (345,800 acres) of the planning unit. Forty-five percent of this land is potentially available for timber harvest. With the growing need for timber, it is critical that these

lands be managed effectively. The U.S. Forest Service is currently
working under a five year timber action plan to designate areas for
harvest. The timber action plan requires a continually updated timber
inventory.

The planning unit has a long history of livestock grazing. In the
early 1900's much of the area was overgrazed, resulting in the near
destruction of prime grazing land. Within the Southern San Juan Moun-
tains Planning Unit, 9,500 cattle and 25,600 sheep are pastured on the
grasslands. Management of these grazing lands is another concern of the
U.S. Forest Service.

Because of the volcanic history of much of the planning unit, there
are local areas which are highly mineralized. An extensive mining in-
dustry was developed during the last century near Jasper and Crater
Creek, and from Platoro Reservoir northwest to Elwood Pass.

The rugged topography and the resulting local climatic regimes of
the Southern San Juan Mountains Planning Unit result in many different
habitats, and create a diversity of vegetation and wildlife communities
within a small geographic area. Human influences have caused even more
diversity by creating large areas in various stages of succession or
disclimax.

The vegetation and wildlife form a loose and elastic "skin" over
the geology and topography of an area. This skin is in a state of
constant ebb and flow to adjust to changes made in the area. There
are small adjustments made when a bear rips apart a rotten log and
licks up the ants. Large adjustments are made when a forest fire burns
portions of the area. Man's activities often change the pattern and
rate of the ebb and flow of this living skin. For some reason, when
the ebb and flow adversely affect man's structures and activities,
it is considered catastrophic, even if the same adjustments have been
going on for thousands of years preceding man's arrival.

Fire is a natural part of the ecosystem in the planning unit.
Periodic lightning or man caused fires have burned and reburned the
area, creating a mosaic of successional stages that contribute to the
complex vegetation types presently occurring in the planning unit. A
succession of species replace each other as the environment changes
and the first species are no longer able to compete effectively. In
the late 1880's a fire covering over 404,000 hectares (1,000,000 acres)

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burned much of the planning unit and north-central New Mexico. Evidence of this and many other fires are still seen in the planning unit as complex mixed forest, pure aspen stands, dead snags, dense young aspen stands, and depressed timberline.

Actual mining activities have had only a slight effect on the ecosystems in the planning unit. After 100 years, only a few crumbling buildings and tailings piles remain from a booming mining era. However, the search for minerals brought thousands of people into the area and the impact of the roads and towns they built are still present.

Demand for the timber of the southern San Juan Mountains began in the mining era to provide lumber for mills and towns, and timbers for mine tunnels and railroads. Today the demand is increasing. Removing the trees by logging sets an area back to an earlier stage of succession. Early successional stages have a wide diversity of species and provide habitat for many animals. Carefully managed logging can remove an overmature stand of timber and allow regrowth for future harvesting. Improper logging techniques can cause erosion or land mass movement. Slash left in a logged area slows or damages regrowth.

Grazing in an area may keep the meadows in a state of disclimax. Cattle have a tendency to feed on certain palatable grasses. Overgrazing removes these grasses and encourages the growth of unpalatable forbs, or the invasion of sage brush or Gambel's oak. Overgrazing by sheep above timberline increases erosion potential. Moderate grazing by livestock and browsing by wildlife helps maintain grasslands in a stable state.

The sage and rabbit brush areas are located in the eastern and southern portions of the planning unit. This sparsely vegetated cover type indicates a semi-arid climate and a moderate amount of disturbance, such as overgrazing. At the upper edge of the sage and rabbit brush zone patches of piñon-juniper forest form an insular mosaic with the sage. The piñon-juniper forest is not extensive in the planning unit. It forms a sparse forest and the understory is often overgrazed.

Ponderosa pine is often mixed with piñon-juniper at the lower edge of its range, and with Douglas fir at the upper extent of its range. Ponderosa pine is seldom found in stands with more than 70% crown closure. The open stands permit a well-developed understory of

grasses or shrubs. Oak and Ponderosa pine often occur together in the
San Juan National Forest. Ponderosa pine has been extensively logged
in the western part of the planning unit, and is being replaced by
Gambel's oak. Gambel's oak is most often found mixed with Ponderosa
pine, aspen, or as pure stands. This shrub, up to 5 meters high, forms
impenetrable thickets with small meadow openings. This cover type is
good habitat for big game animals.

Douglas fir and white fir occur between the Ponderosa pine and
the spruce/fir zones in the planning unit. Dense stands consisting of
both species are found on north facing slopes at the lower extent of
their range, and are found on all aspects at higher elevations. White
fir is sometimes an indicator of disturbance, and both species are
used for timber.

Engelmann spruce and subalpine fir form the most extensive coniferous
forest in the planning unit. This dense forest extends from the Doug-
las fir/white fir belt to timberline. At timberline the Engelmann
spruce forms Krummholz, an ecotone between the forest and alpine tundra.
Here the growth form is stunted and twisted by harsh weather conditions.
Engelmann spruce and subalpine fir are a valuable timber resource and
are extensively logged in the planning unit.

Bristlecone pine, limber pine, and Mexican white pine grow in
sparse stands on rocky exposed sites. These species are infrequent
and are valuable to man only for the scenic beauty caused by their
twisted growth form.

Aspen is the predominant deciduous tree species in the planning
unit. Aspen grows from 2,450 m (7,500 feet) up to over 3,600 m
(11,000 feet) and forms mixes with Ponderosa pine, oak, Douglas fir,
white fir, Englemann spruce, subalpine fir, and cottonwood, as well as
occurring in pure stands. Aspen is often an indicator of disturbance.
Areas burned within the past 50 years frequently have dense aspen stands,
usually with a coniferous understory which will eventually overtop and
shade out aspen seedlings. Aspen also forms a topoedaphic climax in
steep, dry, rocky locations where conifer seedlings are unable to become
established. Formerly regarded as worthless for timber, aspen is being
considered for logging as the demand for wood products increases.

Narrow-leaf cottonwood, blue spruce, and willow form the riparian

community in the planning unit. This association grows on the flood plains of all major streams and in areas with a high water table. The riparian species help prevent erosion of stream banks and subsequent deterioration of water quality.

There are many grassland areas in the planning unit. These have been classified by soil moisture level which controls the species growing in the meadows, and further divided into alpine and lower grasslands. There are only a few agricultural areas included on the classification. These are on private lands within the boundaries of the planning unit. Wet meadows are dominated by sedges and forbs. Mesic meadows have a luxuriant growth of grasses and provide most of the range in the planning unit. Dry meadows are also dominated by grasses and forbs, but the productivity is less than for mesic meadows. Sparsely vegetated areas are those with grass or sagebrush forming less than 50% of the ground cover, with the remaining area being bare rock or soil. Above timberline all grasslands are referred to as tundra. Wet tundra is usually soggy through most of the growing season and supports a lush mat of sedges. Mesic tundra is dominated by forbs such as paintbrush and alpine avens, and grasses. Dry tundra has both sedges and grasses with many cushion plants. Sparsely vegetated tundra is on exposed snowfree sites, or in areas of extensive snow accumulation. A few wind blown sedges, cushion plants and crustose lichens grow among the rocks. Grasslands in the planning unit are used extensively for grazing. Cattle graze the valley bottoms and meadows at lower elevations. Sheep graze in the subalpine meadows and the tundra. Various wild herbivors use all grasslands in the planning unit.

Areas of bare rock occur at all elevations in the planning unit. These are rock outcrops with little or no vegetation, or gravel bars in streams which change with the spring floods. Rock outcrops often expose mineral veins which attracted prospectors to the region in the late 1800's. Gravel deposits are needed today for building and maintaining roads.

There are several large reservoirs in the planning unit, as well as numerous small man-made and natural lakes. These help control flooding from spring run-off, and provide water for the communities in the San Luis Valley, and the lower reaches of the Rio Grande and the Colorado River.

SECTION B

U.S. FOREST SERVICE CONCERNS

AND INVOLVEMENT

P.V. Krebs, INSTAAR

Demands on the resources of the National Forests are rapidly increasing. Recreational use of public lands for camping, fishing, hunting, skiing, hiking, and backpacking increases at a rate of 40% every 10 years. Timber consumption is expected to increase 18-32% per decade until the year 2,000. Twelve percent more rangeland in the forest is used each decade for grazing sheep and cattle. More water is needed each year to support the growing population of the United States. Minerals and energy sources are increasingly important considerations as the National Forest lands include most of the nation's non-ferrous metal and energy reserves.

The Multiple Use-Sustained Yield Act of 1974 (PL86-517) requires that the use of the National Forest resources provide for a combination of public benefits. An inventory of resources is needed to define basic land use allocations as stipulated in the Resources Planning Act of 1974 (PL93-378). The soundness of any land use policy is dependent upon the accuracy, depth, source, and timeliness of the resource information.

Improving and speeding the nationwide inventory and evaluation of timber and related resources is the objective of the newly created Resources Evaluation Techniques Program at the Rocky Mountain Forest and Range Experiment Station in Ft. Collins, Colorado. The major effort is to improve methods for assessing the quantity and quality of renewable resources nationwide. These renewable resources are timber, water, range forage, fish and wildlife habitat, and outdoor recreation opportunities.

National demands for products from the land are constantly increasing and have emphasized the need to upgrade and speed resource inventories and evaluation processes. Through the Forest and Rangeland Renewable Resources

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Planning Act of 1974, Congress requires the U.S. Forest Service to take a leadership role in making periodic national assessments of the nation's forest and rangeland renewable resources for planning purposes. Working in cooperation with other Federal and State agencies, and with private organizations, the U.S. Forest Service completed the first resource assessment at the end of 1975. This was presented to Congress by the President in March, 1976. Updated inventories and assessments will be made in 1980, and every ten years thereafter.

To meet these objectives, currently used inventory techniques must be evaluated and modified if necessary. If suitable methods are non-existant, development and documentation of techniques will have to be done. Ways must be divised to evaluate and to use the inventory data in speeding and enhancing multi-resource planning. This necessitates computerized methods for storing, retrieving, and analyzing inventory data in formats useful to resource planners and managers. LANDSAT MSS data analysis combined with ancillary resource data sets can assist in the planning process and in determining the management direction.

The San Juan and Rio Grande National Forests in south-central Colorado (Region 2, U.S. Forest Service) and the Carson National Forest in north-central New Mexico (Region 3, U.S. Forest Service) are in the process of developing a Land Use Plan for the 283,500 hectares (700,000 acres) Southern San Juan Mountains Planning Unit. Resource specialists from the Forest Service are working with the public and Federal, State, and local agencies. The Institute of Arctic and Alpine Research (INSTAAR) at the University of Colorado, and the Laboratory for Applications of Remote Sensing (LARS) of Purdue University are among these.

The objectives of the Southern San Juan Mountains Planning Unit study, as stated by the U.S. Forest Service, are:

1. Develop a Land Use Plan providing management direction for the protection, maintenance, and use of the land.

2. Determine the pattern of uses and activities on a logical basis to meet public need.

3. Define and evaluate the environmental and socio-economic impact for various levels of development and use so that the most desirable combination can be selected.

4. Evaluate the cost (trade-offs) of resource values lost and socio-economic opportunities foregone where conflicts occur.

An environmental Statement describing the proposed management decisions will be sent to the President's Council on Environmental Quality. The statement will discuss the proposed action, adverse and favorable environmental impacts, the relationship between short-term land use and maintenance of long-term productivity, irreversible and irretrievable commitment of resources, and alternatives to the proposed land use decisions.

Contributions to the planning process which were provided by this LANDSAT project are:

1. a vegetation classification for 404,858 hectares (1,000,000 acres) derived from computer-aided analysis techniques applied to geometrically corrected LANDSAT MSS data. The display products may be thematic maps of covertypes at a 1:24,000 scale or other desired scales, and tabular data of acreage estimates and percentage of area for each covertype;

2. an overlay of topographic data onto the LANDSAT classification to create a multichannel data set. This data set includes separate channels for 23 spectral-informational classes of vegetation, elevation in 100 meter increments, slope aspect in 12 categories, and percent of slope in 6 categories;

3. conversion of the results tape of the multichannel data set to the "R-2" and "R-3" mapper formats. These are on-line computer programs in Region 2 and Region 3 designed to manipulate combinations of resource data. This provides "in-house" capability to the U.S. Forest Service to select data combinations for day-to-day management needs which are at a more detailed level than the requirements of unit planning;

4. computerized combinations of U.S. Forest Service selected parameters from the multichannel data set for specific applications, e.g., proposed timber sales;

5. a technique of mapping landform features from LANDSAT MSS imagery. Support data included 2° topographic and geologic maps and reports of detailed work done in the area. Drainage pattern maps and maps of landslide areas are examples of this approach.

These National Forests are members of the user community who want
to become involved in applications of remote sensing analysis. Recognition
and acceptance of this technology development by the user community depends
on documentation and understanding of the system and its benefits. There
is as great a need for the researchers and analysts to have an understanding
of the concerns and data needs of the user. The communication gap which
frequently exists between the users and the researchers creates misunder-
standings. Remote sensing technology becomes the scape goat. The re-
searchers produce unwanted products and/or the users misuse or do not use
the analysis results.

To avoid these problems constant interaction was encouraged among
the U.S. Forest Service, INSTAAR, and LARS. In October 1974, INSTAAR
started monthly informal meetings with the U.S. Forest Service. These
took place at the regional office, headquarters of the National Forests,
and the district offices, rathern than asking the Forest Service personnel
to come to INSTAAR in Boulder, Colorado. These meetings served to gradually
introduce the Forest Service personnel to the techniques of analysis,
products, and potential applications of LANDSAT MSS data; and to assist
INSTAAR personnel in understanding the Forest Service terminology, planning
concerns, and data needs. During the summer of 1975 U.S. Forest Service
personnel periodically joined the INSTAAR field team to point out specific
locations having unique features in which the Forest Service was interested.
An analyst from LARS was also in the field with INSTAAR for three days to gain
a broad perspective of the study area. A week's training session, designed
specifically for this project, at LARS was attended by five people from
INSTAAR and six from the U.S. Forest Service. In October, 1975, a U.S.
Forest Service-INSTAAR-LARS meeting was held at the headquarters of the
San Juan National Forest in Durango, Colorado.

Eventually, the cooperation among the groups stimulated visits by
U.S. Forest Service personnel to the Mountain Research Station of the
University of Colorado, 48 kilometers (30 miles) west of Boulder. The
INSTAAR team was based at these facilities. These visits were viewed
as an indication of the recognition and acceptance of the LANDSAT follow-
on project. It should be remembered that the distance from the National
Forests is considerable. Representatives of the three National Forests
and Region 2 offices came to the Mountain Research Station to meet with

Dr. Robert Price (GSFC) during his site visit in March 1976. The U.S. Forest Service formulated many ideas which extended the activities beyond the proposed scope of the project. The original objective of the project was to apply LANDSAT MSS data analysis to the U.S. Forest Service long-range planning process. However, the detail and flexibility of the resource information derived from this study has provided a data base for day-to-day management.

The outcome of these interactions defined the direction of the project using computer-aided analysis techniques and image interpretation of LANDSAT MSS data. Letters of support from U.S. Forest Service personnel who are using products resulting from this project are found in Appendix C.

SECTION C

VEGETATION CLASSIFICATION

AND EVALUATION

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Over the past decade, notable progress has been made in the development of computer-aided analysis techniques (CAAT) involving the application of pattern recognition theory to multispectral scanner data. The basic procedure applied to an analysis of multispectral scanner data normally includes:

1. Defining a group of spectral classes (training classes);

2. Specifying the location of these training classes to a statistical algorithm which calculates defined statistical parameters;

3. Utilizing the calculated statistics to "train" a pattern recognition algorithm;

4. Classifying each data point or group of data points within the data set of interest (such as an entire LANDSAT frame) into one of the training classes;

5. Displaying the classification results in map and/or tabular format, according to the specifications of the analyst;

6. Evaluating the classification results.

During the past few years, experience at LARS has shown that there are many possible refinements in the methods utilized by the analysts for obtaining the training classes (step 1 above) and in the procedures for evaluating the results (step 6 above), whereas the rest of the procedure varies little from one type of analysis to another.

C. 1. Comparison and Selection of Analysis Techniques.

Over the past several years, "supervised" analysis techniques, which involve a training sample approach, and "non-supervised" or clustering techniques have been used with considerable success to define the training classes. In the supervised approach, the analyst

selects areas of known cover types and specifies these to the computer
as training fields, using a system of X-Y coordinates. The training
field statistics are obtained for each cover type category. The
entire data set is then classified, using these training statistics, .
and the results are evaluated. These types of classifications are
referred to as supervised because the analyst must locate specific
areas of known cover types to train the computer.

During the LANDSAT-1 investigations (NASA contract No. NAS5-
21880) the supervised approach was found to be extremely difficult
to utilize in an area of complex vegetation types and rugged terrain.
This was because the supervised approach requires the analyst to
select homogenous training samples which would be representative of
all possible variations in spectral response for each cover type.
In mountainous terrain, selection of such a training data set proved .
extremely difficult because of the spectral differences caused by
variations in elevation, slope and aspect, as well as because of the
many spectral differences in the cover types themselves.

In the non-supervised, or clustering approach, an algorithm is
employed which divides a designated area into a number of spectrally
distinct classes. The analyst must specify the number of spectral
classes into which the data will be divided. The spectral classes
as defined by the clustering algorithm are then used to classify the
data, but at this point the analyst does not know what cover type
is associated with each of the spectral classes. Normally, after
the classification is completed, the analyst will identify the cover
type represented by each spectral class, using available support data
such as cover type maps or aerial photographs. A classification using
this procedure is called non-supervised because the analyst need not
define particular portions of the data for use as training fields,
but must only specify the number of spectral classes into which the
data are to be divided. Because of the difficulty in knowing how many
spectral classes are included in a single species or cover type, previous
work (Smeeds, 1970; Hoffer, 1974) had indicated that the non-supervised
approach was usually more satisfactory when analyzing MSS data obtained
over wildland areas.

Due to the vegetative and topographic complexity of the Southern

San Juan Mountain Planning Unit, use of the supervised approach was
not feasible in this study. Utilization of the non-supervised approach
required defining such a high number of spectral classes that identi-
fication of each spectral class into a specific cover type (or
category of interest) proved extremely difficult. Therefore, a more
effective procedure has been developed to accurately classify and map
the forest cover types in an area of such complex spectral character-
istics. A technique defined here as the "modified cluster" technique
(Hoffer, et al , 1974; Fleming, et al , 1975) was used during the
LANDSAT-1 and SKYLAB investigations. This modified cluster approach
was further refined and tested throughout this LANDSAT-2 study.

C.2.   The Modified-Cluster Technique.

Modified cluster is an effective and efficient technique for
defining training statistics. This technique is essentially a hybrid
of the supervised and non-supervised training approaches which over-
come many of the disadvantages inherent in both of these other techniques.
Supervised training is limited by the unknown relationship between
categories of importance and spectral classes. Non-supervised training
is suboptimal since the analyst must estimate and specify the number of
spectral classes present in the data. Also, numerous spectral classes
are usually required which makes proper interpretation of the results
extremely difficult. This hybrid technique, modified cluster, over-
comes these obstacles by allowing a more effective analyst/data inter-
action. The modified cluster technique was found to require less
computer time to develop training statistics and to produce statistics
which would yield a higher classification performance (Fleming, et al,
1975).

The modified cluster technique is comprised of four basic steps
including:

Step 1 - define training blocks dispersed over the entire study
site, with optimumally three to five cover types adequately represented
in each training area;

Step 2 - cluster each training block separately; compare cluster
map with the support data, and recluster if necessary;

Step 3 - combine the results of all training blocks, using the

separability algorithm, and develop a single set of training statistics; and

Step 4 - classify the training blocks as a preliminary test of training statistics, modify statistics deck, if necessary; then classify the entire study area.

Each of these steps are discussed in detail. The basic goal when selecting training areas is to obtain a representative sample of all spectral classes present in the study area. To do this, a representative sample of each cover type, including spectral subclasses caused by variations in slope, aspect, and crown density, must be included in at least one, but preferably two or more training blocks. Selection of training blocks throughout the entire study area (Figure C.1.) provides a better sample of each cover type and reduces the problems encountered in extrapolating the training statistics to the entire data set.

Since each cluster class must be accurately identified, informational support data of good quality (e.g., maps, field data, and aerial photography) must be available for all selected training areas. Classification accuracy is heavily dependent upon the precision with which the cluster classes were identified and described. Thus, the more accurate the identification of the spectral cluster training classes, the more accurate the final classification. Selection of training blocks that have precisely locatable features such as a lake, rock outcropping, etc., allows easier and more accurate correlation between the support data and cluster classes.

Experimentation with different LANDSAT-1, SKYLAB, and LANDSAT-2 data sets has indicated that the optimum size for a training bock is approximately 40 lines by 40 columns (1600 pixels or resolution elements). This size area is small enough to be clustered relatively easily into about 16 cluster classes, each having approximately 100 pixels.

Experimentation has also indicated that selecting and clustering a training block with three to five spectrally similar cover types optimizes the spectral separability between these cover types. Additionally, this procedure allows the analyst to determine whether the various cover types of interest can be defined on the basis of their spectral reflectances. In other words, if a single cluster class is identified as representing several different cover types, a clear

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Figure C.1.   A black and white LANDSAT-1 Band 5 image showing 10 of the 11 training areas utilized with the modified clustering technique to develop training statistics.

relationship does not exist between the spectral reflectance and the cover types of interest. On the other hand, several cluster classes may be identified as the same covertype and can be grouped. The MSS data for each training block are clustered into a number of spectral classes, independent of all other training blocks. In this manner, a greater number of spectral classes are obtained, and the amount of computer time required is greatly reduced as compared to clustering all training blocks together.

Table C.1 shows a comparison between clustering seven training blocks separately and clustering all of them together (Hoffer, 1974). In this case, by separate clustering, the computer time was reduced by nearly 86%, and the number of spectral classes was increased from 30 to 76. Although there may be some duplication of spectral classes when clustering independently, these can be identified and grouped later. More importantly, any classes that represent mixtures of several cover types or pixels that are on the edge between cover types can be identified and deleted without significantly reducing the number of spectral classes.

Table C.1. Comparison between the non-supervised and modified cluster methods for defining training statistics.

	Methods Used	
	Non-Supervised	Modified Cluster
Number of Pixels	7844	7844
Number of Training Blocks	7	7
Number of Spectral Classes	30	76
Computer Time (Minutes)	68.1	9.7

The number of cluster classes into which each block is divided varies as a function of the data variability. The parameters which may be used to help choose the proper number of clusters are closely related. These parameters include average transformed divergence, highest minimum transformed divergence, total variability of all

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cluster classes, and a transformed scatter ratio (Sinding-Larson, 1974). The transformed scatter ratio, which estimates how well the data are divided, was used throughout this investigation to select the "optimum" number of cluster classes for a training area. To utilize this ratio effectively, each training area is clustered into 12 through 16 classes and the transformed scatter ratio is calculated for each of the different number of classes. The optimal class number is selected by minimizing the transformed scatter ratio. If the minimum number is either 12 or 16 (rather than between 12 and 16), the transformed scatter ratio is then calculated for the next cluster number (e.g., 11 or 17 respectively). This process continues until a minimum scatter ratio is found.

After the "optimum" number of cluster classes is found for a training block, each cluster class must be identified as to the actual cover type it represents by overlaying the cluster map with the support data. For this LANDSAT-2 study, a base cover type map for each training block was prepared through interpretation of the underflight color infrared photography. The aerial photography could be used directly by projecting the photography onto the cluster map using an overhead projector, zoom transfer scope, or vertical sketchmaster. By using the aerial photography directly, more precise and detailed information could be obtained for each cluster class than by simply using cover type maps. Using this approach, one drawback was encountered which was attributed to the equipment available for this investigation. Identification of cover types is improved when working in stereo mode. To view aerial photography in stereo while being projected onto the cluster maps could have added to the ease of photointerpretation.

Because several statistics decks are produced by clustering the data from each training block separately, the separability algorithm is used to combine the cluster classes into information-spectral classes of the final statistics deck. The saturating transformed divergence value (obtained from the separability algorithm) is a measure of the distance between classes in multidimensional space. This measure, which ranges in value from 0 to 2000, is referred to as the divergence value. Higher divergence values indicate class pairs which are more separable. Past experience of LARS researchers suggests that class pairs

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with divergence values of 1700 or greater will generally yield a
bimodal distribution when grouped (which violates the basic assumption
of the maximum-likelihood, Gaussian classifier). Thus, class pairs
which have divergence values less than 1700 may be grouped; class
pairs which have divergence values greater than 1700 are kept separate.

Since a large number of cluster classes are usually obtained by
clustering each area independently, simultaneous comparison of all
class pairs with divergence values less than 1700 is difficult. For
this reason, the combination of similar cluster classes is performed
in a series of steps. The first step is to calculate the divergence
value of each pair of cluster classes. Because cover types are included
more than once in the many training blocks, there should be several
similar spectral classes for each cover type. Combining all pairs
with a divergence value of 1000 or less reduced the number of cluster
classes by nearly one-half. The low divergence value of 1000 indicated
that the spectral classes for that pair were very similar. To distin-
guish these combined classes from the original cluster classes, the
combined classes are referred to as "spectral classes".

The second step is to calculate the divergence value for each
pair of spectral classes. In this step, all spectral class pairs with
a divergence value of 1500 or less are combined. The value of 1500 was
selected because there are usually still too many pairs with a divergence
value of less than 1700 to allow easy grouping of the spectral classes
(and not many below 1200). When combining the spectral classes, the
vegetative (or other) cover type is checked for each cluster included
in the spectral class grouping. Any spectral class with more than one
cover type present (mixed cover types) is deleted unless the mixed cover-
type is a desired informational class (e.g., coniferous-deciduous forest).
The combined spectral classes are then identified and named, and con-
sequently are called "spectral informational" classes.

This process of calculating divergence values and combining classes
may be repeated several times until the desired separability is achieved
between the spectral-informational classes. If more detail is needed
for one or more cover types, it may be desirable not to combine some
spectral-informational classes and therefore accept some misclassification
between those classes. This confusion between classes may show when

classifying coniferous/deciduous mix and deciduous/coniferous mix
forest as separate classes. This is where the objectives of the ana-
lysis become important in deciding the disposition of these classes.

The training areas should be classified as a final check before
classifying the entire study area to test the training statistics. The
classification results can then be compared with the support data to make
sure no errors were made in labelling classes or that any desirable
classes were deleted, or combined that should not have been. If no errors
were made, the entire study area is classified with the maximum likeli-
hood classifier.

A recently developed analysis procedure, referred to as the "ECHO"
(Extraction and Classification of Homogeneous Objects) classifier, has been
developed. This technique involves the use of an algorithm which first
defines the boundary around an area of similar spectral characteristics
and then the area within the boundary is classified into a single spectral
class. This procedure is somewhat similar to the "Per Field" classifier
which has been used previously at LARS, except that with the "Per Field"
classifier, the analyst must specify the area to be classified (boundaries).
The ECHO classifier has the capability of specifying the boundary as
part of the computer analysis procedure.

C.3. Results of the LANDSAT Data Analysis.

The application of computer-aided analysis techniques (CAAT) to the
LANDSAT multispectral scanner data obtained on September 20, 1973 pro-
duced a number of significant results. A geometrically corrected (1:24,000
scale) digital data tape containing the four wavelength bands of LANDSAT
data, plus five channels of topographic data (elevation, slope, and aspect)
was utilized throughout this phase of the study. The "modified cluster"
techniques and classification evaluation techniques previously described
in Section C.2 were used for the analysis.

The first step in the analysis involved definition of the spectral
classes that would characterize the area. Initial work with the modified
clustering technique resulted in 166 statistically defined cluster classes
from the 11 training blocks within the test site. This was far too many
to work with effectively, and it was not clear that all 166 spectral classes
were really significant from an information content standpoint. In other

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words, did each of these classes really contain meaningful information?

The feature selection algorithm within LARSYS was used. Spectral classes having separabilities of less than 1500 were grouped. Interpretation of these results indicated that the spectral classes to be grouped usually were not significantly different in terms of information content (e.g., an aspen stand having 70% crown closure was grouped with an aspen stand having 75% crown closure). Detailed analysis of the spectral classes involved, combining the feature selection algorithm with the modified cluster technique, ultimately resulted in the definition of 25 statistically separable spectral classes each of which had meaningful information content. The characteristics of these spectral-informational classes were determined by comparison of the aerial underflight photography (Mission 75-101, June 25, 1975) with the computer printouts quadrangle by quadrangle of the LANDSAT data classification. The descriptions of these spectral-informational classes for each quadrangle are listed in Appendix A. Table C.2 gives a general description of the spectral-informational classes over the study area.

The 25 spectral-informational classes resulting from this work are thought to effectively represent the spectral characteristics of this study area. Effective man-machine interaction is necessary to define such spectral-information classes. This phase of the study was probably the most critical part of the entire analysis procedure. Considerable time and effort were required on the part of a skilled analyst who was familiar with classification procedures in cooperation with an ecologist who was familiar with the ecology and characteristics of the study area.

One of the techniques developed during the course of the investigation aided in the process of defining the spectral informational classes. This technique of a bi-spectral plot, designed by Michael D. Fleming of LARS, uses a computer program to plot the spectral response of cluster classes in a graphic two-dimensional array. The average of the two visible wavelength bands were plotted against the average of the two near infrared wavelength bands. However, one could also obtain approximately the same results by plotting Band 5 (0.6-0.7 micrometers) against Band 7 (0.8-1.1 micrometers) data. An example of such a plot showing the spectral informational classes used in the final classification of this data set is shown in Figure C.2. This display aids in the interpretation

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Table C.2. Generalized description of spectral informational classes.

Spectral Class   Description

A   Water, some shadow

B   80-100% spruce/fir or douglas fir

C   70-80% spruce/fir or douglas fir

D   70-80% spruce/fir, douglas fir;
                             with up to 10% aspen

E   Mix class predominantly coniferous
                             with deciduous

F   Mix class, predominantly deciduous
                             with some conifers

G   Low density conifer with grass, in-
                             cludes some edge effect

H   Low density conifer with grass, in-
                             cludes krummholz, ponderosa
                             pine, and piñon/juniper

I   Rocky, dry grassland

J   Mix class, approximately half deci-
                             duous, half coniferous

K   100% aspen

L   100% aspen

M   100% aspen

N   100% aspen

O   Low density mix class, predominantly
                             deciduous

P   Moist grassland

Q   Moist meadow, often with willows

R   Mesic meadow

S   Moist grassland, irrigated pasture

T   Dry grassland, often tundra

U   Dry grassland

V   Rocky, dry grassland, less than 50%
                             density vegetation

W   Bare rock and soil, exposed

X   Bad data

Y   Bad data
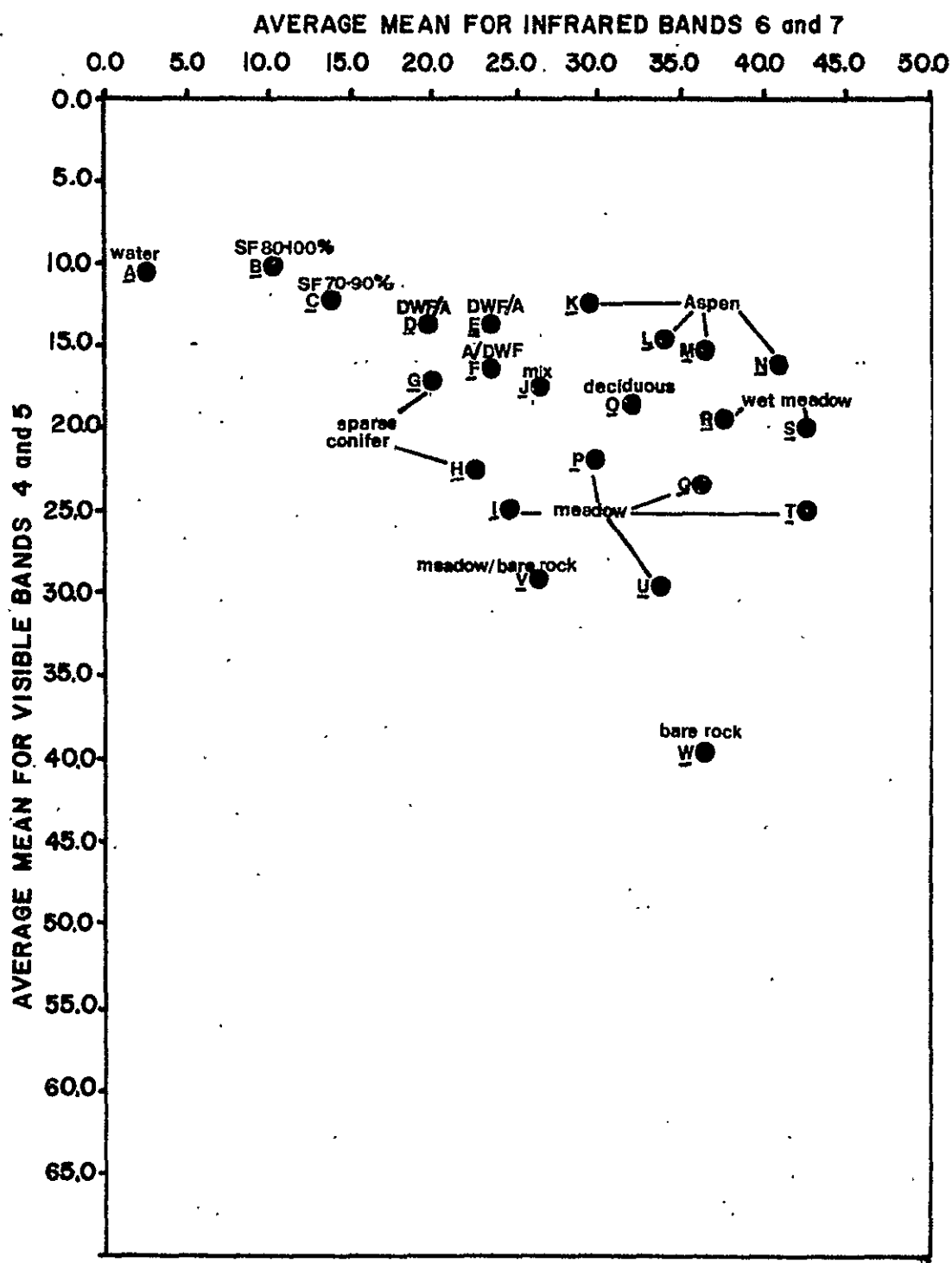
Figure C.2. Bi-spectral plot of the class means for the 25 spectral informational classes developed for the Southern San Juan Mountains Planning Unit.

of the relationships among spectral classes.

Examination of Figure C.2 quickly reveals that water, appearing in the upper left of the figure, has a very low response in the near infrared channels and a rather low response in the visible channels. On the other hand, bare rock has a very high response in the visible channels and a rather high response in the near infrared channels, so it appears in the lower right portion of the plot. The spectral classes for meadow and aspen tend to have a much higher infrared reflectance than the coniferous forest cover. Because the meadow has generally a higher response in the visible channels than the aspen, the various individual spectral classes of meadow can be grouped together rather effectively, whereas, the four individual spectral classes for aspen define a distinct sequence of increasing spectral response in both wavelength regions from one spectral class to the next. Aspen, spectral class L, has a higher spectral response in both the visible and near IR than aspen, spectral class K. These differences may be due to clonal variations and the color changes of the leaves at the time of the LANDSAT pass (September 20, 1973). The spectral classes representing spruce/fir have the lowest spectral response of any of the vegetative categories, particularly in the infrared channels, but also in the visible channels.

This two-dimensional plot clearly shows the interrelationships between the spectral classes and informational classes of interest. Based upon this plot, one can see that certain informational classes will generally be found in a particular region of two-dimensional space, at least in this one data set. Displaying the spectral information in such a two-dimensional plot was a useful tool in better understanding the numerical data generated through the various computer programs utilized in the analysis of this data.

Effective definition of the spectral-informational classes present in the study area could not have been accomplished without the use of the underflight aerial photography. It would have been possible to define a group of spectral classes without such photography but it would not have been possible to relate such spectral classes to the informational categories of interest or significance. Spectral data alone is not applicable to the needs of the user community.

As previously indicated, the output of the classification results can be shown in either map or tabular format. Since the entire study area is so large, it was not practical to display detailed cover type maps for the entire region in this report. Therefore, to illustrate the quality and type of product that was generated in the computer classification process, one U.S.G.S. 7 1/2 minute quadrangle was selected from each of the three forests involved in the study area, and will be used as example quadrangles for displaying and discussing the classification results. These example quadrangles or demonstration areas include the Chromo NE quadrangle in the San Juan National Forest, the Platoro quadrangle in the Rio Grande National Forest, and the Brazos Peak NE quadrangle in the Carson National Forest. A series of classification outputs showing the flexibility of the classification are included for each of these demonstration quadrangles. Figures C.3 - C.8 show the Platoro quadrangle in the Rio Grande National Forest and include a map showing the 25 spectral informational classes defined in the analysis sequence (Figure C.3), a generalized vegetation map of major cover types (Figure C.4), a generalized vegetation map obtained using the ECHO classifier (Figure C.5), a generalized vegetation map obtained from the ECHO classification but displayed using a CalComp Plotter (Figure C.6), a map emphasizing the forest cover types present (Figure C.7), and a map emphasizing the grassland cover types (Figure C.8). Figures C.9 - C.14 show the same series of maps for the Chromo NE quadrangle in the San Juan National Forest and Figures C.15 - C.20 show a similar series of figures for the Brazos Peak NE quadrangle in the Carson National Forest.

To provide additional data of potential value to the U.S. Forest Service, the coordinates of the corners of each quadrangle present in the study area were defined and the percentage of the samples classified into various categories were calculated for each of the 31 quadrangles. Table C.3 shows these acreage estimates on a percentage basis for the generalized vegetation map of the entire study area. The acreage values in Tables C.3 - C.5 are broad approximations because the spectral class descriptions were taken from the generalized descriptions in Table C.2, and not from the specific descriptions of each quadrangle in Appendix A.

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The categories tabulated include water, coniferous forest, mixed forest (a category combining coniferous and deciduous forest cover), deciduous forest, grassland, exposed rock and soil, and bad data. The bad data category was necessary because a number of scan lines of data from the satellite were extremely noisy and contained poor quality data. Therefore, instead of trying to classify this poor quality data and obtaining erroneous classifications, a bad data category was defined and this noisy data was classified as such in the analysis sequence.

Table C.4 contains the results of the tabulation of the classification map emphasizing forest cover types. This output contains the same water, exposed rock and soil, grassland, and bad data line tabulations as contained in the generalized vegetation map, but then divides the coniferous forest, mixed forest and deciduous forest categories into detailed forest cover type categories. The detailed forest cover types as defined and requested by the U.S. Forest Service include nine different categories.

Table C.5 summarized the results emphasizing the grassland characteristics of the study area. In this case, all of the forest cover is grouped into a single category but the grassland is separated into mesic grassland, dry grassland, and dry and rocky grassland.

Tabular information, such as contained in Tables C.3 - C.5, emphasizes one of the major advantages for digital processing techniques. Once the classification has been achieved, it is relatively simple to tabulate the data points classified into each of the different categories. However, the value of such tabular information is largely a function of the classification accuracy that had been achieved initially. The maps and tables presented provide a good indication of the types of output products that could be achieved in displaying classification results. The examples shown are only a representation of the results that were actually obtained for the entire 31 quadrangle area of the Southern San Juan Mountains Planning Unit.

Table C.3. Percentage tabulation for generalized vegetation for each quadrangle in the planning unit. All figures are given as percentages.

QUADRANGLE   PERCENTAGE OF SAMPLES CLASSIFIED INTO:

	WATER	CONIFER	MIX	DECID	GRASS	EXPOSED	BADATA
Wolf NW	0.3	25.7	33.1	19.2	19.2	2.1	0.4
Wolf NE	0.3	37.9	29.0	11.4	19.7	1.4	0.3
Elwood	0.3	45.9	15.9	3.8	32.5	1.7	0.0
Summitville	0.2	41.6	12.9	4.8	35.8	4.1	0.6
Jasper	0.3	39.2	17.8	7.1	33.2	1.8	0.6
Greenie Mt.	0.0	27.3	22.5	5.4	43.3	1.5	0.1
Fulcher	0.0	5.5	0.7	0.9	45.3	47.1	0.4
Wolf SW	0.0	8.6	41.4	21.1	26.4	0.5	2.0
Wolf SE	0.3	41.9	24.6	12.3	17.8	1.7	1.5
Summit Pk.	1.2	33.9	14.0	5.2	40.8	3.9	1.0
Platoro	2.2	41.0	12.9	3.6	37.8	1.9	0.6
Red Mtn.	0.2	31.7	29.0	7.6	30.8	0.2	0.5
Terrace	0.9	19.9	19.5	2.5	53.1	1.5	2.7
Centro	0.0	1.4	0.1	0.4	39.9	55.2	3.0
Chromo NW	0.2	9.5	39.9	12.6	37.0	0.6	0.1
Chromo NE	0.3	13.1	38.2	35.0	12.3	0.2	0.8
Chama NW	1.4	34.0	21.0	12.1	28.0	2.0	1.6
Chama NE	0.6	29.1	13.6	4.8	47.0	2.9	2.0
Spectacle L.	0.2	28.2	26.2	7.0	35.2	0.1	3.1
La Jara C.	0.0	17.2	17.2	1.9	58.8	0.4	4.4

Table C.3. (Cont.)

QUADRANGLE	WATER	CONIFER	MIX	DECID	GRASS	EXPOSED	BADATA
				PERCENTAGE OF SAMPLES CLASSIFIED INTO:			
Vicente C.	0.0	4.3	0.3	0.1	51.3	39.4	4.6
Chromo SW	0.0	7.9	29.4	13.2	45.4	3.5	0.5
Chromo SE	0.0	4.0	25.4	36.4	32.3	0.6	1.2
Chama SW	0.2	19.4	32.7	26.3	18.2	0.8	2.4
Chama SE	0.1	20.4	23.8	20.9	30.7	1.7	2.5
Cumbres	0.2	29.3	17.9	6.5	42.8	1.1	2.2
Oiser	0.0	15.3	16.6	5.1	55.6	5.1	2.2
Fox Ck.	0.0	10.5	4.4	1.2	69.7	10.8	3.4
Brazos NW	0.0	20.8	23.0	4.5	47.6	1.8	2.2
Brazos NE	0.0	17.3	14.8	6.4	56.0	2.6	2.8
Bighorn Pk.	0.0	19.7	10.7	2.9	60.5	2.5	3.7
Total	0.3	22.6	20.3	9.8	38.8	6.5	1.7

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Table C.4. Percentage tabulation for vegetation with a forest emphasis for each quadrangle of the planning unit. All figures are given as percentages.

QUADRANGLE

PERCENTAGE OF SAMPLES CLASSIFIED INTO:

	WATER	BADDATA	EXPOSED	GRASS	SF-100	SF-70-80	SF-DWF/A
Wolf NW	0.3	0.4	2.1	12.9	3.1	20.5	13.6
Wolf NE	0.3	0.3	1.4	13.0	4.9	30.3	7.0
Elwood	0.3	0.0	1.7	20.2	6.7	33.0	1.9
Summitville	0.2	0.6	4.1	21.5	6.4	29.7	1.0
Jasper	0.3	0.6	1.8	22.6	4.7	28.1	1.7
Greenie Mt.	0.0	0.1	1.5	37.7	1.1	17.3	3.2
Fulcher	0.0	0.4	47.1	42.2	0.0	1.1	0.1
Wolf SW	0.0	2.0	0.5	20.7	0.2	5.9	9.2
Wolf SE	0.3	1.5	1.7	11.7	7.4	31.8	7.8
Summit Pk.	1.2	1.0	3.9	28.0	7.1	23.3	1.8
Platoro	2.2	0.6	1.9	23.3	9.2	27.6	0.9
Red Mtn.	0.2	0.5	0.2	21.1	2.1	26.1	4.0
Terrace	0.9	2.7	1.5	46.8	0.3	7.4	2.3
Centro	0.0	3.0	55.2	38.9	0.0	0.0	0.0
Chromo NW	0.2	0.1	0.6	29.8	0.2	5.6	4.2
Chromo NE	0.3	0.8	0.2	8.0	0.9	11.3	14.6
Chama NW	1.4	1.6	2.0	18.2	6.8	24.2	7.4
Chama NE	0.6	2.0	2.9	30.6	3.4	21.7	1.7
Spectacle L.	0.2	3.1	0.1	24.5	0.9	20.5	4.7

Table C.4. (Cont.)

QUADRANGLE	PERCENTAGE OF SAMPLES CLASSIFIED INTO:					
	MIX-PP/O	MIX-D/C	C-30%/GRAS	A 100%	A 90-100%	A-50%
Wolf NW	19.4	6.1	4.3	7.5	4.0	5.6
Wolf NE	22.0	4.8	5.7	3.4	1.8	5.3
Elwood	14.0	2.3	11.6	0.3	0.5	7.5
Summitville	12.0	3.4	10.0	0.2	0.4	10.4
Jasper	16.1	5.7	12.3	0.7	0.3	5.1
Greenie Mt.	19.2	4.7	13.2	0.3	0.1	1.5
Fulcher	0.7	0.2	6.0	0.0	0.2	2.0
Wolf SW	32.3	11.9	3.9	3.7	2.2	7.7
Wolf Se	16.8	5.3	5.8	3.5	2.3	4.2
Summit Pk.	12.2	3.5	7.4	0.3	0.5	9.9
Platoro	11.9	2.7	7.5	0.1	0.2	11.8
Red Mtn.	25.0	6.1	7.0	0.6	0.2	6.7
Terrace	17.2	2.1	17.6	0.3	0.1	0.9
Centro	0.1	0.2	1.5	0.0	0.1	0.9
Chromo NW	35.7	10.0	5.7	0.7	0.4	6.8
Chromo NE	23.6	14.4	2.0	13.0	4.5	6.3
Chama NW	13.5	5.0	6.1	3.9	1.8	8.2
Chama NE	11.9	3.5	6.6	0.3	0.2	14.6
Spectacle L.	21.5	4.9	12.3	1.1	0.4	5.7

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Table C.4. (Cont.)

QUADRANGLE	PERCENTAGE OF SAMPLES CLASSIFIED INTO:						
	WATER	BADDATA	EXPOSED	GRASS	SF-100	SF-70-80	SF-DWF/A
La Jara C.	0.0	4.4	0.4	52.0	0.2	8.2	1.7
Vicente C.	0.0	4.6	39.4	49.8	0.0	1.4	0.0
Chromo SW	0.0	0.5	3.5	40.5	0.1	4.8	2.9
Chromo SE	0.0	1.2	0.6	23.3	0.0	2.9	5.2
Chama SW	0.2	2.4	0.8	12.5	1.7	15.6	12.4
Chama SE	0.1	2.5	1.7	17.3	0.8	18.1	6.5
Cumbres	0.2	2.2	1.1	28.2	1.1	24.3	2.7
Oiser	0.0	2.2	5.1	46.0	0.3	9.2	2.5
Fox Ck.	0.0	3.4	10.8	65.7	0.1	3.1	0.5
Brazos NW	0.0	2.2	1.8	36.2	0.8	14.4	2.4
Brazos NE	0.0	2.8	2.6	49.9	0.5	10.4	2.0
Bighorn Pk.	0.0	3.7	2.5	55.2	0.1	9.9	1.6
Total	0.3	1.7	6.5	30.6	2.3	15.7	4.1

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Table C.4. (Cont.)

QUADRANGLE	PERCENTAGE OF SAMPLES CLASSIFIED INTO:					
	MIX-PP/O	MIX-D/C	C-30%/GRAS	A 100%	A 90-100%	A-50%
La Jara C.	15.5	1.7	14.4	0.1	0.0	1.2
Vicente C.	0.3	0.1	4.3	0.0	0.0	0.2
Chromo SW	26.5	9.3	4.2	0.9	0.8	6.0
Chromo SE	20.2	18.6	1.6	7.2	4.6	14.6
Chama SW	20.3	13.7	3.8	7.4	2.5	6.5
Chama SE	17.3	9.0	2.7	6.6	2.8	14.7
Cumbres	15.2	3.7	6.2	0.8	0.8	13.6
Oiser	14.2	3.9	10.0	0.7	0.2	5.8
Fox Ck.	3.9	0.9	10.5	0.2	0.0	1.0
Brazos NW	20.5	2.8	8.5	0.9	0.4	9.0
Brazos NE	12.8	4.1	9.1	1.5	0.5	3.8
Bighorn Pk.	9.1	1.9	14.4	0.8	0.1	0.7
Total	16.2	5.4	7.6	2.2	1.1	6.4

Table C.5. Percentage tabulation for vegetation with grassland emphasis for the planning unit. All figures are given as percentages.

QUADRANGLE | PERCENTAGE OF SAMPLES CLASSIFIED INTO:

QUADRANGLE	WATER	FOREST	EXPOSED	BADDATA	MESIC GRASS	DRY GRASS	DRY&ROCKY	MOIST
Wolf NW	0.3	75.8	2.1	0.4	8.4	4.3	3.6	5.1
Wolf NE	0.3	75.5	1.4	0.3	9.6	3.2	2.1	7.6
Elwood	0.3	59.4	1.7	0.0	18.4	7.2	3.9	9.1
Summitville	0.2	53.8	4.1	0.6	19.8	8.2	4.5	8.8
Jasper	0.3	57.7	1.8	0.6	17.0	6.7	5.8	10.1
Greenie Mt.	0.0	46.3	1.5	0.1	14.5	3.8	26.2	7.6
Fulcher	0.0	2.8	47.1	0.4	7.6	4.7	35.2	2.3
Wolf SW	0.0	68.6	0.5	2.0	8.2	4.9	4.6	11.2
Wolf SE	0.3	76.0	1.7	1.5	8.7	3.9	3.9	3.9
Summit Pk.	1.2	49.6	3.9	1.0	16.4	15.1	7.1	5.8
Platoro	2.2	53.3	1.9	0.6	18.7	10.0	4.2	9.1
Red Mtn.	0.2	64.9	0.2	0.5	13.1	5.4	2.3	13.5
Terrace	0.9	29.6	1.5	2.7	18.5	2.9	36.5	7.4
Centro	0.0	0.6	55.2	3.0	2.3	2.4	35.0	1.4
Chromo NW	0.2	58.2	0.6	0.1	11.0	6.8	5.5	17.5
Chromo NE	0.3	85.4	0.2	0.8	5.3	1.7	1.0	5.3
Chama NW	1.4	64.1	2.0	1.6	12.8	6.9	5.8	5.6
Chama NE	0.6	43.5	2.9	2.0	20.4	14.2	7.0	9.4
Spectacle L.	0.2	54.6	0.1	3.1	17.4	3.5	6.2	14.9

Table C.5. (Cont.)

QUADRANGLE	PERCENTAGE OF SAMPLES CLASSIFIED INTO:							
	WATER	FOREST	EXPOSED	BADDATA	MESIC GRASS	DRY GRASS	DRY&ROCKY	MOIST
La Jara C.	0.0	27.6	0.4	4.4	15.6	6.6	33.0	12.4
Vicente C.	0.0	1.8	39.4	4.6	4.4	0.7	.48.2	0.8
Chromo SW	0.0	47.6	3.5	0.5	·7.9	9.7	13.9	16.8
Chromo SE	0.0	64.7	0.6	1.2	10.2	6.2	1.9	15.2
Chama SW	0.2	76.3	0.8	2.4	7.7	2.6	2.5	7.4
Chama SE	0.1	63.6	1.7	2.5	14.9	7.6	2.2	7.5
Cumbres	0.2	49.7	1.1	2.2	18.6	11.8	3.7	12.7
Oiser	0.0	31.2	5.1	2.2	15.4	20.6	11.8	13.7
Fox Ck.	0.0	8.8	10.8	3.4	11.4	1.8	60.7	3.2
Brazos NW	0.0	.42.7	1.8	2.2	17.1	14.9	3.1	18.2
Brazos NE	0.0	32.2	2.6	2.8	12.5	15.4	17.6	16.9
Bighorn Pk.	0.0	23.6	.2.5	3.7	15.0	2.9	44.5	7.8
Total	0.3	48.1	6.5	1.7	12.9	7.0	14.3	9.3

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Figure C.3. Classification map for Platoro quadrangle showing the 25 spectral-informational classes.

Figure C.4. **Classification map for Platoro quadrangle showing the generalized vegetation informational classes.**

COLORADO
MIKE FLEMING
GENERALIZED VEGETATION - QUADRANGLE - PLATORO

LABORATORY FOR APPLICATIONS OF REMOTE SENSING
PURDUE UNIVERSITY

CLASSES

	CLASSIFICATION STUDY	604262115		CLASSIFIED	FEB 11,1976
RUN NUMBER	....	73069304	DATE DATA TAKEN	... SEPT 20,1973
FLIGHT LINE	... 142417132	COL	TIME DATA TAKEN	.... 1013 HOURS
DATA TAPE/FILE NUMBER	.. 2896/ 1		PLATFORM ALTITUDE	..3062000 FEET
REFORMATTING DATE, FEB	6,1976		GROUND HEADING	..... 180 DEGREES

CLASSIFICATION TAPE/FILE NUMBER ... 325/ 2

CHANNELS USED

CHANNEL 1	SPECTRAL BAND 0.50 TO 0.60 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 2	SPECTRAL BAND 0.60 TO 0.70 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 3	SPECTRAL BAND 0.70 TO 0.80 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 4	SPECTRAL BAND 0.80 TO 1.10 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0

SYMBOL	CLASS	GROUP		SYMBOL	CLASS	GROUP
W	A	WATER		/	N	DECID
O	B	CONIFER		/	O	DECID
O	C	CONIFER			P	GRASS
O	D	CONIFER			Q	GRASS
X	E	MIX		/	R	DECID
X	F	MIX			S	GRASS
	G	GRASS			T	GRASS
O	H	CONIFER			U	GRASS
	I	GRASS			V	GRASS
X	J	MIX		+	W	EXPOSED
/	K	DECID		S	X	RADATA
/	L	DECID		S	Y	RADATA
/	M	DECID				

Figure C.5. Classification map for Platoro quadrangle showing the genera-
lized vegetation informational classes when the ECHO classi-
fier was utilized.

Figure C.6. CalComp line map for the Platoro quadrangle ECHO classifica-
tion showing the generalized vegetation.

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PURDUE UNIVERSITY

CALCOMP CLASSIFICATION MAP

CLASSIFICATION STUDY 608279013   CLASSIFIED   MAR 22,1976
RUN NUMBER............. 73069304   DATE DATA TAKEN... 9 / 20 / 73
FLIGHTLINE.... 142417132   COL   TIME DATA TAKEN..... 1013 HOURS
DATA TAPE/FILE NUMBER.. 2896/ 1   PLATFORM ALTITUDE. 3062000 FEET
REFORMATTING DATE. FEB 6,1976   GROUND HEADING..... 180 DEGREES

CLASSIFICATION TAPE/FILE NUMBER ... 328/ 3

PLATORO QUADRANGLE
GENERALIZED VEGETATION MAP
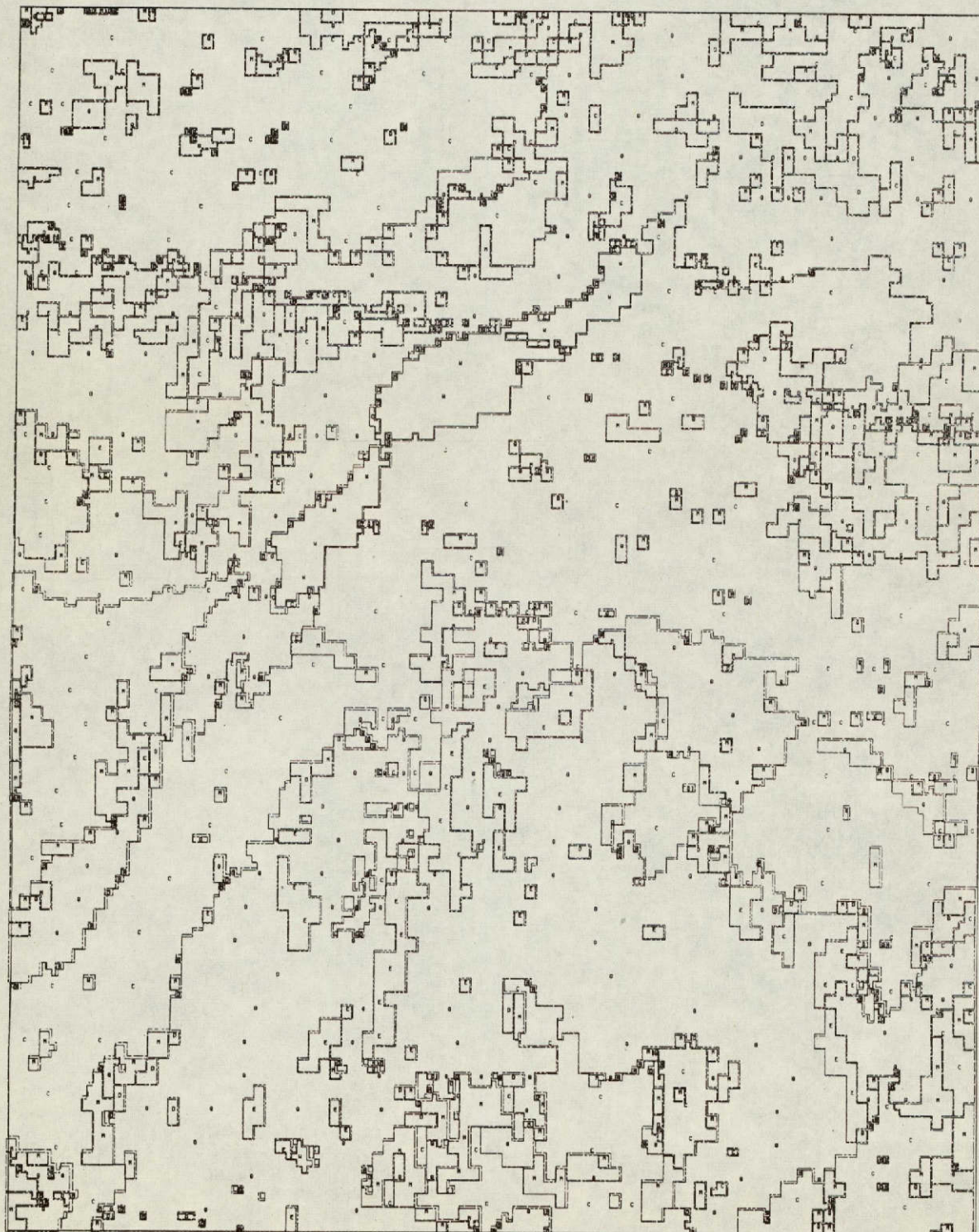
Figure C.7. Classification map for Platoro quadrangle which emphasizes the forest cover types.

COLORADO
MIKE FLEMING
FOREST EMPHASIS - QUADRANGLE - PLATORO

LABORATORY FOR APPLICATIONS OF REMOTE SENSING
PURDUE UNIVERSITY

CLASSIFICATION STUDY 604262115
RUN NUMBER............. 73069304
FLIGHT LINE.. 142417132   COL
DATA TAPE/FILE NUMBER.. 2496/ 1
REFORMATTING DATE. FEB 4,1976

CLASSIFIED   FEB 11,1976
DATE DATA TAKEN... SEPT 20,1973
TIME DATA TAKEN.... 1013 HOURS
PLATFORM ALTITUDE..306?000 FEET
GROUND HEADING..... 180 DEGREES

CLASSIFICATION TAPE/FILE NUMBER ... 325/ 2

CHANNELS USED

CHANNEL 1   SPECTRAL BAND 0.50 TO 0.60 MICROMETERS   CALIBRATION CODE = 1   C0 = 0.0
CHANNEL 2   SPECTRAL BAND 0.60 TO 0.70 MICROMETERS   CALIBRATION CODE = 1   C0 = 0.0
CHANNEL 3   SPECTRAL BAND 0.70 TO 0.80 MICROMETERS   CALIBRATION CODE = 1   C0 = 0.0
CHANNEL 4   SPECTRAL BAND 0.80 TO 1.10 MICROMETERS   CALIBRATION CODE = 1   C0 = 0.0

CLASSES

SYMBOL	CLASS	GROUP	SYMBOL	CLASS	GROUP
W	A	WATER	L	N	A 90-100
S	B	SF-100			MIX-D/C
O	C	SF-70-80	.	O	GRASS
O	D	SF-70-80	.	Q	A -50
X	E	SF-DWF/A	+	R	A -50
/	F	MIX-PP/D		S	GRASS
/	G	-3D/GRAS		T	GRASS
/	H	-3D/GRAS		U	GRASS
	I	GRASS	.	V	GRASS
=	J	MIX-PP/D	+	W	GRAS-?
A	K	A 100	S	Z	BADDATA
A	L	A 100			BADDATA
L	M	A 90-100			

Figure C.8. Classification map for Platoro quadrangle which emphasizes the grassland cover types.

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GRASSLAND EMPHASIS - QUADRANGLE - PLATORO

CLASSIFICATION STUDY 608279013	CLASSIFIED MAR 22,1976
RUN NUMBER............ 73069304	DATE DATA TAKEN... SEPT 20, 1973
FLIGHT LINE... 142417132 COL	TIME DATA TAKEN..... 1013 HOURS
DATA TAPE/FILE NUMBER.. 2896/ 1	PLATFORM ALTITUDE..3062000 FEET
REFORMATTING DATE. FEB 6,1976	GROUND HEADING..... 180 DEGREES

CLASSIFICATION TAPE/FILE NUMBER ... 328/ 3

CHANNELS USED

CHANNEL 1	SPECTRAL BAND 0.50 TO 0.60 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 2	SPECTRAL BAND 0.60 TO 0.70 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 3	SPECTRAL BAND 0.70 TO 0.80 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 4	SPECTRAL BAND 0.80 TO 1.10 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0

SYMBOL	CLASS	GROUP	SYMBOL	CLASS	GROUP
W	A	WATER		N	FOREST
	B	FOREST		O	FOREST
	C	FOREST	X	P	MOIST
	D	FOREST	O	Q	GRASS
	E	FOREST		R	FOREST
	F	FOREST	X	S	MOIST
O	G	GRASS	/	T	DRYGRASS
O	H	GRASS	/	U	DRYGRASS
=	I	DRYROCK	=	V	DRYROCK
	J	FOREST	+	W	EXPOSED
	K	FOREST	S	X	MAPDATA
	L	FOREST	S	Y	MAPDATA
	M	FOREST			

Figure C.9. Classification map for Chromo NE quadrangle showing the 25
spectral informational classes.

Figure C.10. Classification map for Chromo NE quadrangle showing the
generalized vegetation informational classes.

Figure C.11. Classification map for Chromo NE quadrangle showing generalized vegetation informational classes when the ECHO classifier was utilized.
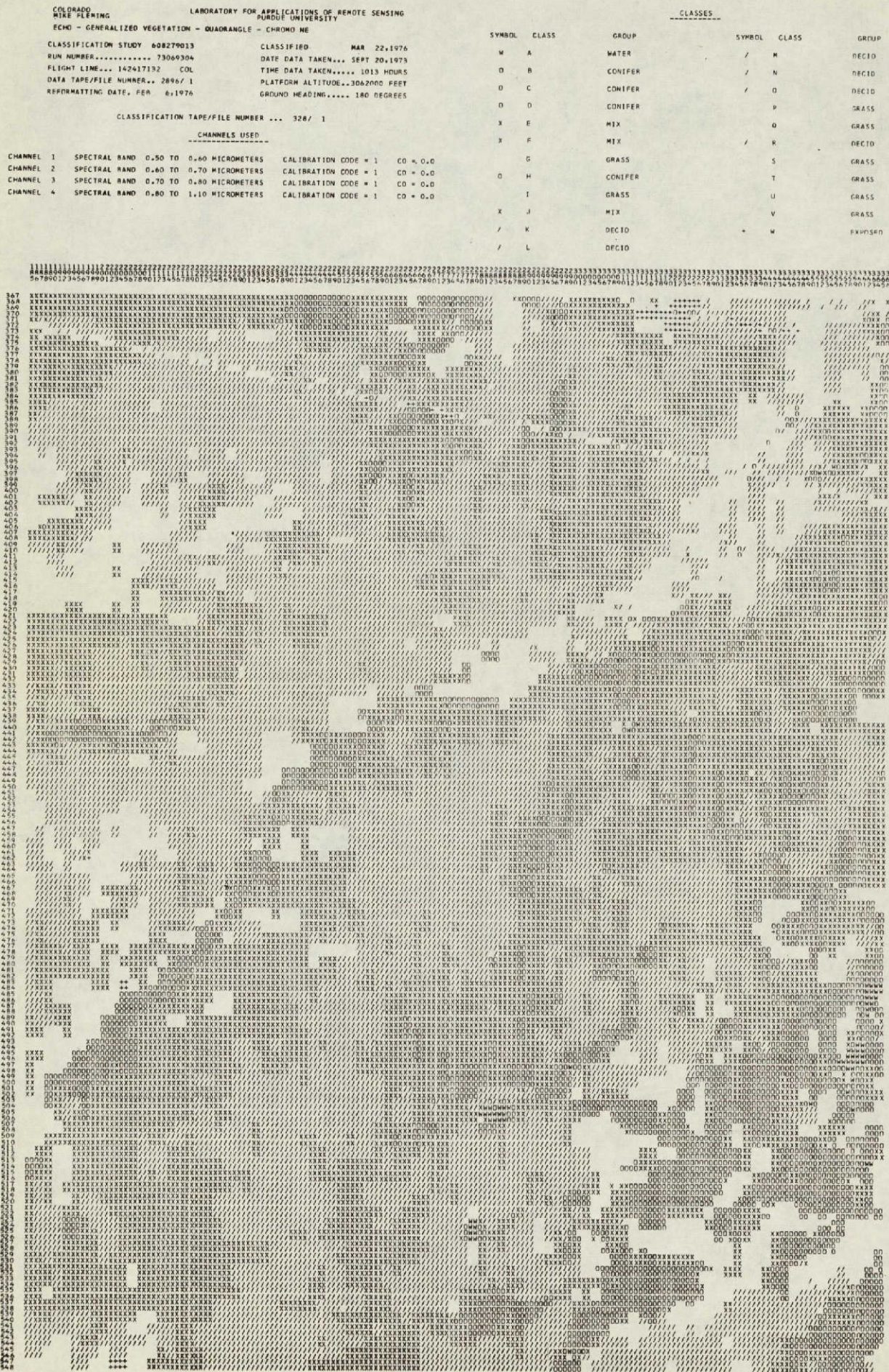
Figure C.12. CalComp line map for the Chromo NE quadrangle ECHO classi-
fication showing the generalized vegetation.

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CALCOMP CLASSIFICATION MAP

CLASSIFICATION STUDY 608279013   CLASSIFIED   MAR 22,1976
RUN NUMBER........... 73069304   DATE DATA TAKEN... 9 / 20 / 73
FLIGHTLINE.... 142417132   COL   TIME DATA TAKEN..... 1013 HOURS
DATA TAPE/FILE NUMBER.. 2896/ 1   PLATFORM ALTITUDE. 3062000 FEET
REFORMATTING DATE. FEB 6,1976   GROUND HEADING..... 180 DEGREES

CLASSIFICATION TAPE/FILE NUMBER ... 328/ 1

CHROMO NE QUADRANGLE
GENERALIZED VEGETATION MAP

Figure C.13. Classification map for Chromo NE quadrangle which emphasizes the forest cover types.
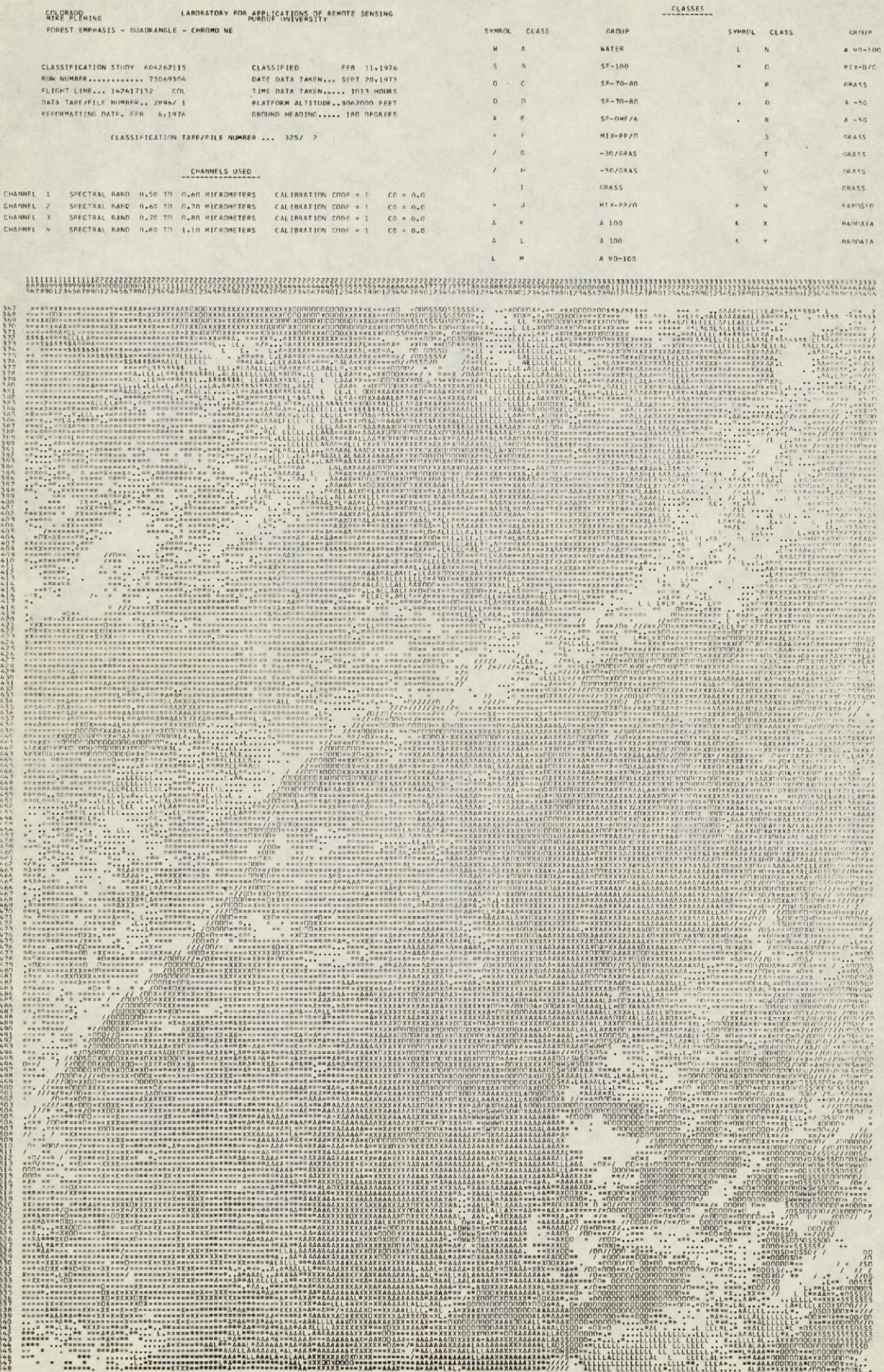
Figure C.14. Classification map for Chromo NE quadrangle which emphasizes the grassland cover types.

Figure C.15. Classification map for Brazos Peak NE quadrangle showing
the 25 spectral-informational classes.

Figure C.16. Classification map for Brazos Peak NE quadrangle showing the generalized vegetation informational classes.

Figure C.17. Classification map for Brazos Peak NE quadrangle showing the generalized vegetation classes when the ECHO classifier was utilized.
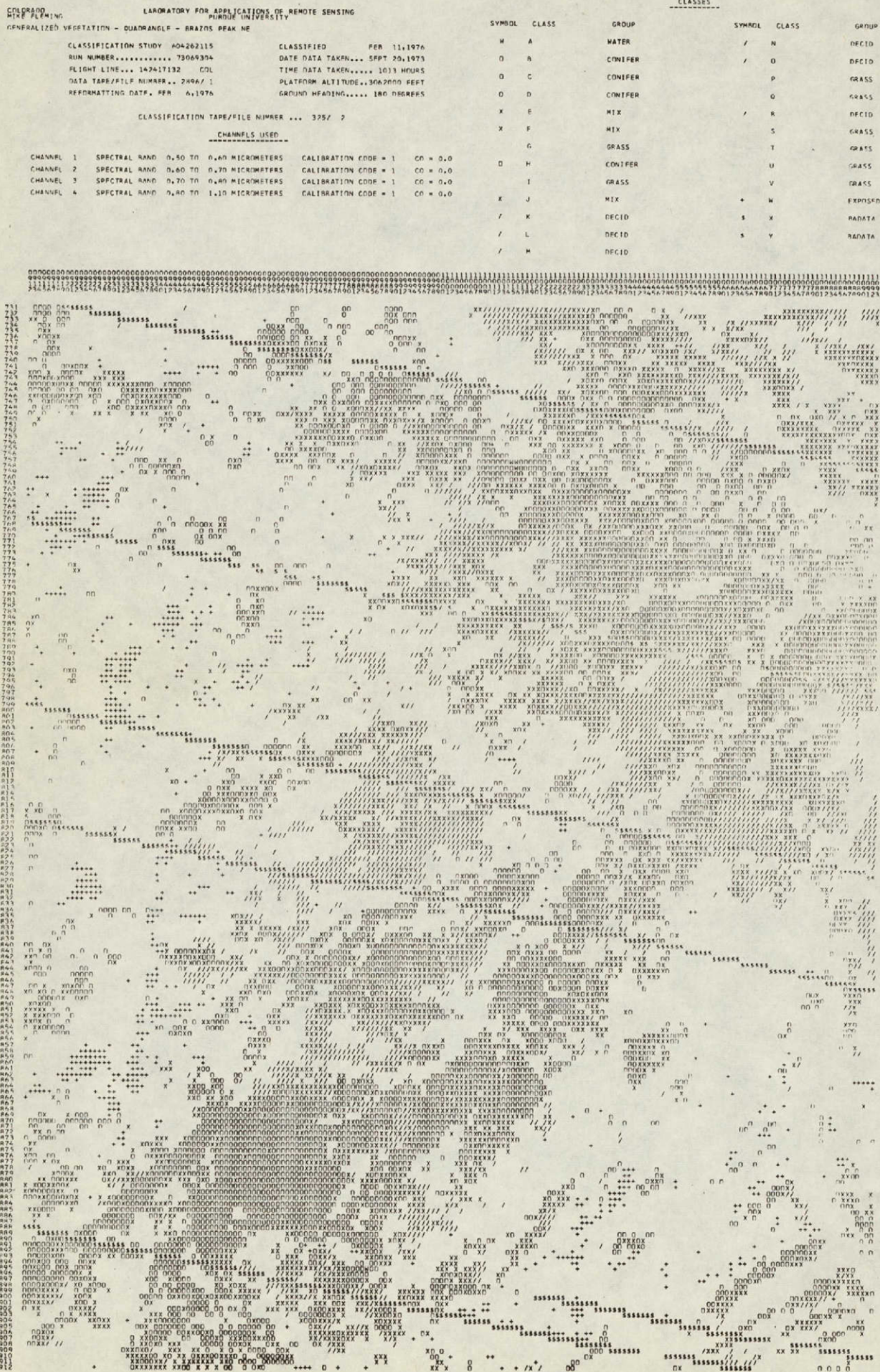
Figure C.18. CalComp line map for the Brazos Peak NE quadrangle ECHO
classification showing the generalized vegetation.

LABORATORY FOR APPLICATIONS OF REMOTE SENSING
PURDUE UNIVERSITY

CALCOMP CLASSIFICATION MAP

CLASSIFICATION STUDY 608279013   CLASSIFIED   MAR 22,1976
RUN NUMBER............. 73069304   DATE DATA TAKEN... 9 / 20 / 73
FLIGHTLINE.... 142417132   COL   TIME DATA TAKEN..... 1013 HOURS
DATA TAPE/FILE NUMBER.. 2896/ 1   PLATFORM ALTITUDE. 3062000 FEET
REFORMATTING DATE. FEB   6,1976   GROUND HEADING..... 180 DEGREES

CLASSIFICATION TAPE/FILE NUMBER ... 328/ 2

BRAZOS PEAK NE QUADRANGLE
GENERALIZED VEGETATION MAP
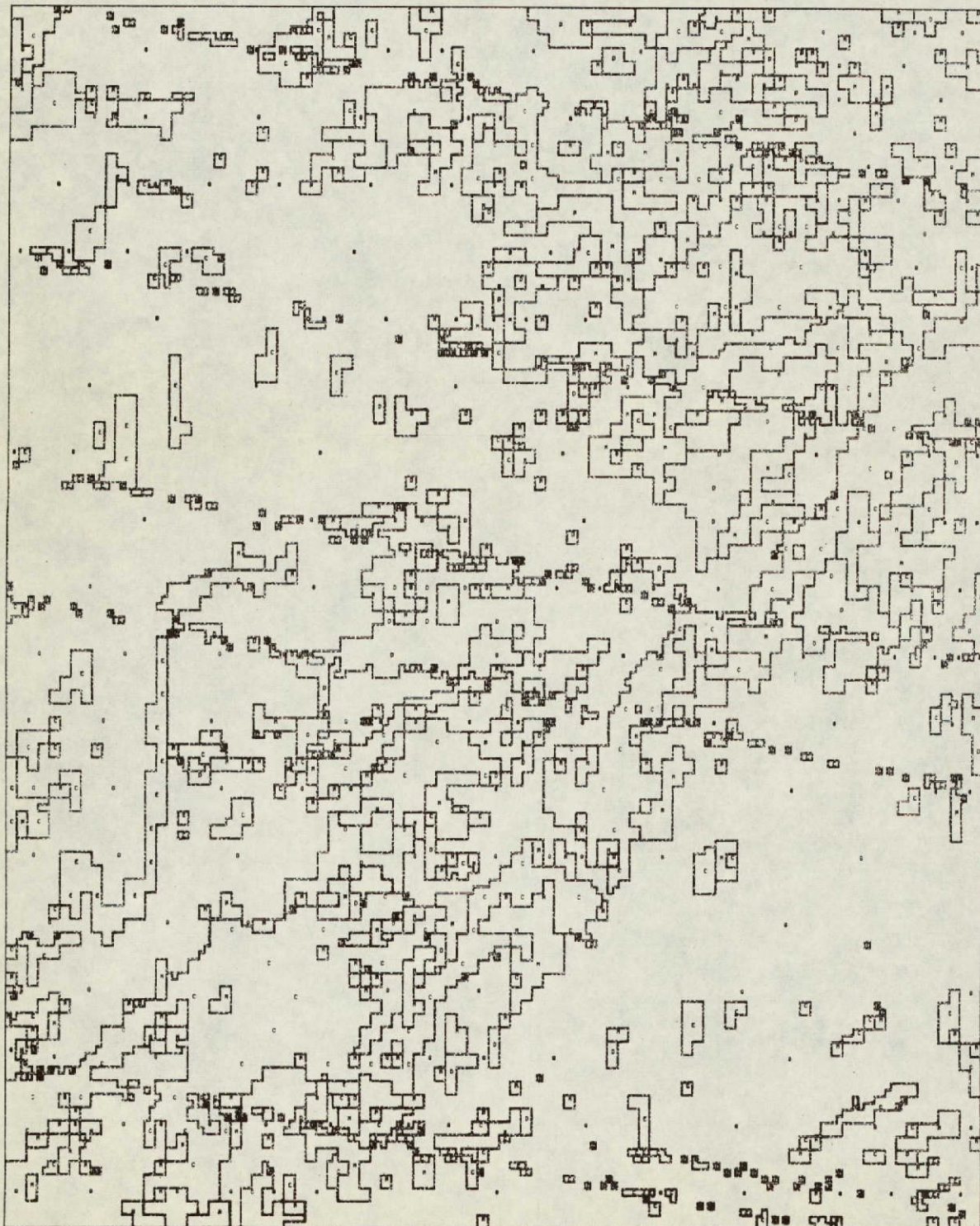
Figure C.19. Classification map for Brazos Peak NE quadrangle which emphasizes the forest cover types.

Figure C.20. Classification map for Brazos Peak NE quadrangle which emphasizes the grassland cover types.

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GRASSLAND EMPHASIS - QUADRANGLE - BRAZOS PEAK NE

CLASSIFICATION STUDY 604262115   CLASSIFIED   FEB 11,1976
RUN NUMBER............ 73069304   DATE DATA TAKEN... SEPT 20,1973
FLIGHT LINE... 147417132   COL   TIME DATA TAKEN.... 1013 HOURS
DATA TAPE/FILE NUMBER.. 2896/ 1   PLATFORM ALTITUDE..3062000 FEET
REFORMATTING DATE. FEB 6,1976   GROUND HEADING..... 180 DEGREES

CLASSIFICATION TAPE/FILE NUMBER ... 325/ 2

CHANNELS USED

CHANNEL 1   SPECTRAL BAND 0.50 TO 0.60 MICROMETERS   CALIBRATION CODE = 1   CO = 0.0
CHANNEL 2   SPECTRAL BAND 0.60 TO 0.70 MICROMETERS   CALIBRATION CODE = 1   CO = 0.0
CHANNEL 3   SPECTRAL BAND 0.70 TO 0.80 MICROMETERS   CALIBRATION CODE = 1   CO = 0.0
CHANNEL 4   SPECTRAL BAND 0.80 TO 1.10 MICROMETERS   CALIBRATION CODE = 1   CO = 0.0

CLASSES

SYMBOL	CLASS	GROUP	SYMBOL	CLASS	GROUP
W	A	WATER		N	FOREST
	B	FOREST		O	FOREST
	C	FOREST	X	P	MOIST
	D	FOREST	□	Q	GRASS
	E	FOREST		R	FOREST
	F	FOREST	X	S	MOIST
O	G	GRASS	/	T	DRYGRASS
□	H	GRASS	/	U	DRYGRASS
=	I	DRYROCK	=	V	DRYROCK
	J	FOREST	+	W	EXPOSED
	K	FOREST	X	X	BADDATA
	L	FOREST	•	Y	BADDATA
	M	FOREST			

C.4. Time Required for Computer Analysis

If computer-aided analysis techniques are to be used to map forest
lands in an operational mode, the procedure must be economical as well
as reliable. In order to study this aspect of the project, careful track
was kept of the amount of computer time and personnel time involved in
various phases of the analysis. Table C.6 shows the computer time re-
quired for analysis of the LANDSAT data in which 11 training blocks were
utilized and a total of 25 spectral classes were involved. This table
shows that for most of the training blocks, 16 spectral clusters were
required to characterize the data in each block. The amount of time
spent for the clustering sequence was nearly as large as that of
classifying the entire area. When one considers that the total number
of data points involved in the clustering phase of the process was only
18,501, whereas the classification process included over a million acres
(1,161,888 data points), it becomes apparent why the clustering must be
conducted using small cluster blocks of data and that the modified cluster
approach offers the opportunity to develop an economical analysis pro-
cedure for the overall classification sequence.

Table C.7 contains both the man hours of analyst time and the
computer time for the classification of the Southern San Juan Mountains
Planning Unit. The pre-processing phase of the analysis included
preparation of the data tapes in order to reformat them from the original
four data tapes received from Goddard to a single data tape used in the
remainder of the analysis procedures. This phase of the process also
included the precision geometric correction which was required in order
to produce a line printer output that was a true 1:24,000 scale and
which could then be overlayed onto the U.S.G.S. 7 1/2 minute topo sheets.
The analysis phase included all of the clustering, comparing, pooling,
test classification, and evaluation of the classification results. As
shown in Table C.7, this analysis phase involved more computer time
than the classification itself. The pre-processing involved a considerable
amount of man-hours. It is hoped that in the future, geometrically cor-
rected data tapes will be generated at a central processing facility,
thereby eliminating the need for such pre-processing costs at various
individual processing facilities such as LARS. In this event, most
of the manpower costs would be spent in developing training statistics

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Table C.6. Computer time required for analysis of LANDSAT MSS data.

TRAINING BLOCK	NO. OF CLUSTERS	COMPUTER TIME (seconds)						
		Clustering	Pooling	Pooling & Comparing 1st	Pooling & Comparing 2nd	Test Classify	Evaluation	Classify Entire Area
1	16	1010						
2	16	890	490		23	567	51	---
3	16	732						
4	13	777						
5	16	775	628	2116				
6	15	759						
7	14	723						
8	13	623			40	612	57	10,254
9	15	755	553					
10	16	805						
11	16	1158						
TOTAL Seconds		9007	1590	2116	63	1179	108	10,254
Minutes		150.0	26.5	35.3	1.1	19.6	1.8	170.9
Hours		2.50	0.44	0.59	0.02	0.33	0.3	2.85

1st

2nd

GRAND TOTAL =   24,323 second = 405.4 minutes = 6.76 hours
@ $250/hr for 1,338,000 acres = $0.0013 per acre.

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Table C.7   Computer time and analyst time required
             for the analysis of the Southern San Juan
             Mountains Planning Unit.

	Man Hours	Computer Time (hrs.)
Preprocessing	20	3.84
Analysis	20	3.61
Classification	1	2.85
Evaluation	9	0.30
TOTAL	50	10.60 hrs.

during the analysis phase of the investigation and the computer time would also be largely spent in the analysis phase of the work.

People working with parallel processing systems have reported that the amount of time required for classifying LANDSAT data can be reduced to less than 1% of what it is at the present time. Such a parallel processing system would cost more per hour of computer time but the overall results would still be to reduce the classification cost to less than 10% of the present cost. However, the development of the training statistics to use in the final classifications would still need to be done with a general purpose digital computer system in an inter-active mode. Since the computer time is already less than 2/10 of a cent per acre, when the entire computer cost for this analysis is considered, it would appear that the computer time for future analysis would be a very modest amount if calculated on a per-acre basis.

C.5. Supportive Data.

The complex terrain and vegetative cover types found in the Southern San Juan Mountains Planning Unit create a whole barrage of problems in simply mapping "ground truth". Even when definitions of cover types and rules for mapping have been established, much remains at the discretion of the person doing field work or photointerpretation. Problems fami-liar to all mappers such as boundary placements, describing crown closures, and community composition, inadequate base maps, phenological changes in grasslands and deciduous trees, under and over exposed photography, and small scale photography combine to yield "ground truth" which is some-thing less than 100% correct.

The MSS data collected by LANDSAT is correct, and the classification of the reflection data by a computer is also correct. The problems come when the analyst or interpreter attempts to assign descriptions to the spectral classes derived from the classification. For the final classification which is being used for the Southern San Juan Mountains Planning Unit, there are 25 spectral-informational classes. Two of these classes are generally high and low reflectance bad data. We have found that for this study it is not valid to extend descriptions for most spectral classes from one side of the Divide to the other, or even from one quadrangle to the one adjacent.

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Each spectral class was described separately for each quadrangle in the study area. This project was fortunate in having color infrared aerial photography from NASA Mission 75-101 which covered the entire planning unit, most of it in stereo. For the spectral class descriptions, a printout of each quadrangle showing all 25 spectral classes was used. Groups of each spectral class were outlined and transferred to 7 1/2' base maps. Poorly represented classes sometimes had as few as 3 pixels in a group, but groups of 10 or more pixels were easier to locate and describe. The outlined areas were then found on the aircraft coverage by correlating the topographic features on the base maps with the topography seen by stereo viewing. A Bausch and Lomb stereoscope with variable magnification was used for viewing the aircraft coverage. The cover types corresponding to each pixel group were used to describe the spectral classes. All photointerpretation for the spectral class descriptions was done by one person in an effort to eliminate the variability resulting from different photointerpreters. Descriptions for each spectral class in each quadrangle are in Appendix A.

A summer of extensive field work in the study area preceded the photointerpretation efforts. Areas of known cover types were used as a standard and the characteristics for each cover type were extended over the entire study area. The film characteristics for this mission are shown in Figure C.21. Ecological parameters for each species, especially elevation, aspect, and moisture gradients, were considered throughout the photointerpretation process. Coverage from NASA Mission 75-101 is good to excellent over the study area. It was flown June 25, 1975 and is entirely cloud free over the study area. The mornings of the last week of June, 1975 were the only period of time in the whole summer that such cloud free coverage could have been obtained. It has proved to be a valuable tool contributing to the completion and usefulness of this project.

There were several problems encountered which influenced all photointerpretation phases of this project. The aircraft photography itself is underexposed at the edges and corners of each frame, making the colors difficult or impossible to interpret. The centers of some frames, especially at lower elevations were overexposed, again making color interpretation difficult. The exposure problems probably caused confusion of
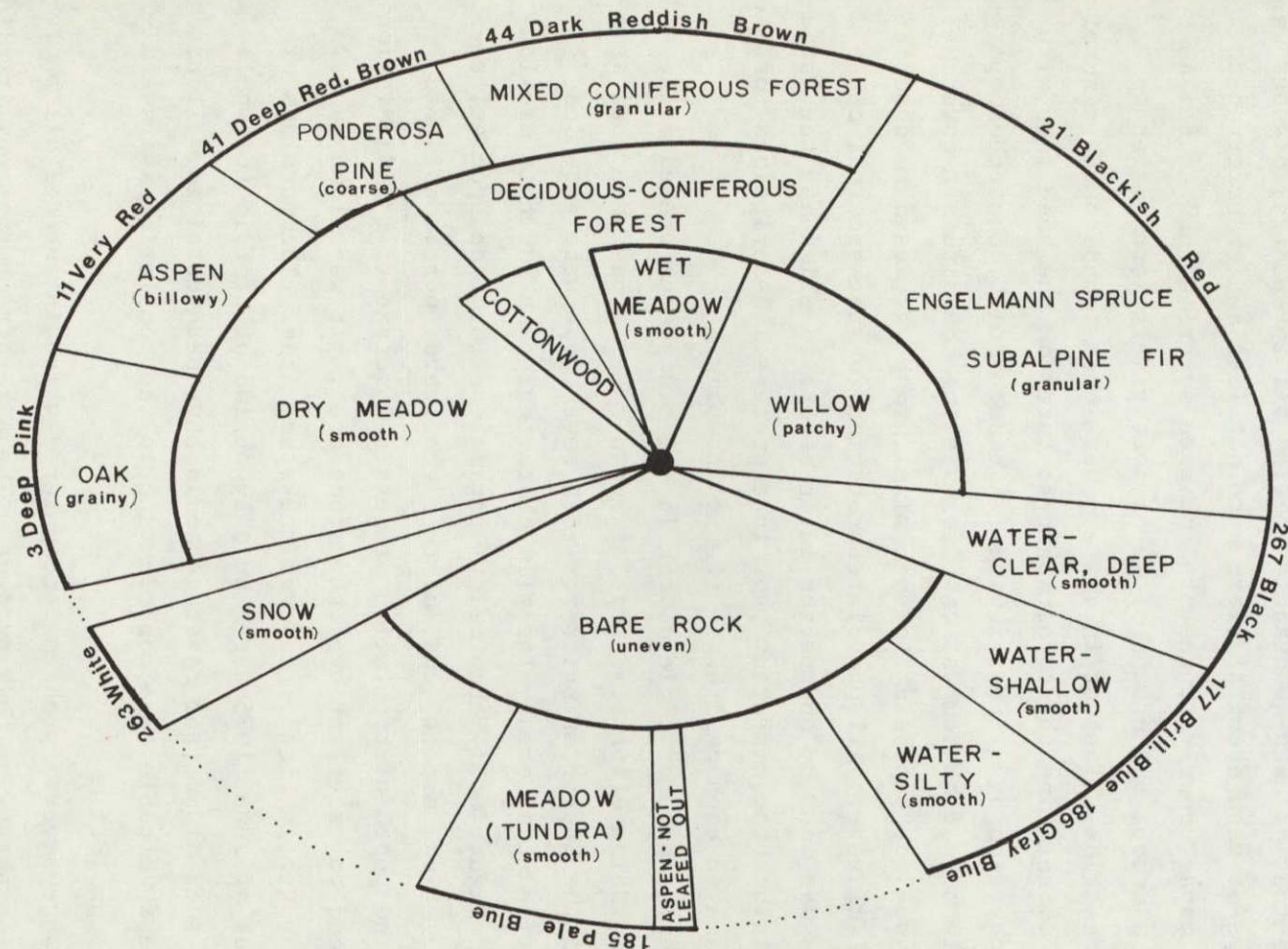
Figure C.21. Film characteristics of cover types. Identification of cover types by air photo-interpretation is based in part on the color and texture of each cover type. No one color or texture describes one cover type. Each color on this diagram represents a point on a continuous spectrum. The color of a cover type falls within a portion of the spectrum. The number and color descriptions are based on National Bureau of Standards ISCC–NBS system of color designations. Key textural characteristics of each cover type are given in parentheses.

douglas fir/white fir, and Englemann spruce/subalpine fir at higher elevations, and confusion of sage, dry meadows, and sparsely vegetated areas at lower elevations. There was heavy snow cover on much of the study area above 3200m (10,500 ft.), especially on northern aspects, due to the heavy snowfall during the winter of 1974-75. The heavy snowcover may have caused spruce/fir crown closure estimates to be lower than actual; confusion among wet, moist, dry, sparsely vegetated tundra and bare rock; and confusion between alpine willow and various tundra types. The late spring also caused late phenological development in the middle elevation ranges for aspen and meadows. This may have resulted in low estimates for crown closure in pure aspen stands and aspen/conifer mixes; and under estimation of aspen composition in mix cover types. However, the phenological differences between aspen and oak during late June enabled the best differentiation of these two types which probably would not have been as good on later coverage. The problem is shown by the low accuracy (51.5%) of the LANDSAT classification for oak using September 20, 1973 data.

At the beginning of the field season in 1975, adequate aircraft coverage was not available for the study area. Therefore, the 1975 field work was structured to provide adequate data for training, describing, and evaluating the CAAT classification in the event aircraft coverage was not obtained. Six 7 1/2' U.S.G.S. quadrangles (Figure C.22) were selected by the U.S. Forest Service personnel to represent the majority of the cover types and topographic variability found in the planning unit. The six quadrangles selected were: Wolf Creek Pass N.E., Chromo N.E., Platoro, Spectacle Lake, Chama Peak S.E., and Brazos Peak N.E. Field data was also collected in portions of Wolf Creek Pass S.E., Chromo S.E., Summitville, Osier, and Bighorn Peak.

The field data was collected using a data point grid overlaid on the 7 1/2' base maps. The data points were 8 pixels apart horizontally and vertically. Each data point in the grid was assigned a unique number within the planning unit.

The most accurate and efficient data collection in the field was usually obtained from a vantage point. Each data point in the field of view was located by corresponding topographic features of the landscape with the U.S.G.S. base maps. With careful observation most of the data

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Figure C.22. Locations for the six 7½' U.S.G.S. quadrangles used for intensive study.

Number Code	Quadrangle
1	Wolf Creek Pass NE
2	Chromo NE
3	Platoro
4	Spectacle Lake
5	Chama Peak SE
6	Brazos Peak NE

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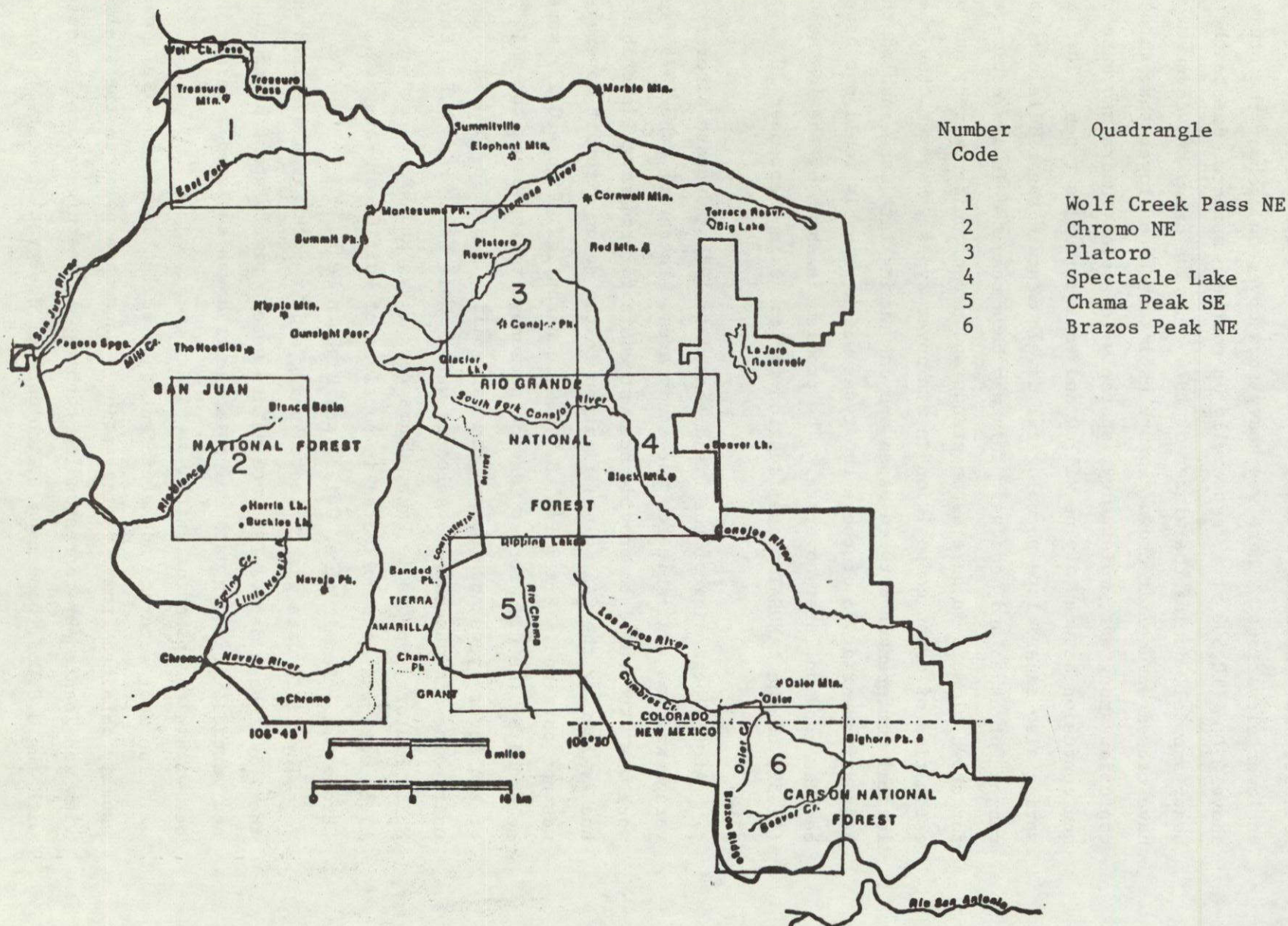
points could be accurately located in the field. Sometimes difficulty was encountered due to changes in river beds, fire regeneration, new logging, or varying photointerpretation definitions by U.S.G.S., but these problems could be resolved with a little extra effort. Binoculars were invaluable for the field work, both in locating data points and for identifying the vegetative cover. Work was not conducted in the early morning, late evening or on stormy days when topographic shadow and haze made identification of tree species difficult.

When a data point had been located, a boundary was drawn on the map indicating the extent of the cover type represented at that point. The area within this boundary must be homogenous with respect to species composition, total crown closure, and community composition. The cover type may extend beyond the boundaries drawn, but the area enclosed indicated what the observer was sure of. No effort was made to extend the boundaries beyond the field of view unless the observer had previously seen the additional area. This provides maximum accuracy of field work without errors resulting from inferences. The cover type was given an alpha-numeric designation according to the vegetation code developed for the field work, and recorded on the maps and in field data books. For each data point the cover type, total crown closure, crown closure by species breakdown, understory if the overstory was less than 100%, and miscellaneous notes were recorded. As much information as was practical was gathered in the field. During further laboratory analysis data can be lumped or disregarded, which is easier than obtaining needed detail after the completion of the field season.

The three months of field work played a critical role in the success of this LANDSAT project. The test data points were used as ground truth for evaluating the LARSYS classification. In the event that NASA had been unable to obtain satisfactory aircraft coverage for the planning unit due to bad weather conditions, the field data would have been the only reliable source of ground truth for most of the planning unit. Field experience aids the researcher in selecting areas for cluster maps used to train the computer in differentiating spectral patterns. Perhaps most important of all, field work gives the researcher an ecological fami-liarity with the study area. The researcher acquires a "gut level" feeling

for the responses of the land and vegetation to topography and distur-
bances, as well as a better understanding of U.S. Forest Service manage-
ment practices and problems.

C.6. Evaluation.

The usefulness of any baseline data is proportional to its accuracy.
The scope and detail of the user needs for data help define acceptable
limits of accuracy. At almost every meeting where CAAT products were
presented to U.S. Forest Service personnel, questions were raised con-
cerning the accuracy and reliability of the cover type classification.

The evaluation of CAAT products is usually made by comparing the
final map with what actually occurs on the ground. This evaluation
may be qualitative or quantitative, depending on the "ground truth"
resources available. Qualitative evaluations were made for all four
classifications that were derived using this data set (see Section C.3).
A quantitative evaluation was made for the final classification which is
being used by the U.S. Forest Service.

There has been much controversy and experimentation on how test
fields for evaluation should be selected, how large they should be,
and how far apart they should be. For this effort three different
sets of test fields were used, all selected from the same six quadrangles
scattered throughout the study area (Figure C.22).
Field Data. The first set of test fields was selected from field work
in the study area. A grid of points was systematically selected by the
computer at 8 pixel intervals. This grid of data points was transferred
to U.S.G.S. 7 1/2' base maps and located and mapped in the field as
described in Section C.5. At the end of the field season the field
maps of all observers were merged onto one map, and a mylar base made
of the information. All information which had been collected for each
data point was checked with the field cover type maps, and organized
in numerical sequence. To facilitate automatic evaluation of the classi-
fication, rectangular test fields were selected from the field cover
type maps. The mylar maps were laid over a computer derived greyscale
and as large a rectangle as possible was drawn around each data point
with the following limitations:

      1) The data point was located somewhere within the test

field, but not necessarily in the center,

    2) There was a 1 pixel border between the test field and the boundary of the cover type,

    3) The test field was homogeneous with respect to cover type, crown closure, and species composition.

Data points on the boundary between two cover types, or within one pixel of the boundary were not used for test fields in order to reduce the edge effect between cover types. Test fields using field data incorporated approximately 1.9% of the entire study area.

Homogeneous Photointerpretation. Upon receipt of NASA mission 75-101 aerial photography in early October, 1975, moderately detailed ground truth through photointerpretation became available for the entire study area (Section C.5). Areas of homogeneous cover type, crown closure, and species composition were outlined on the aircraft coverage and transferred to topographic base maps using contour lines and stereo viewing. The test fields were chosen so that the covertypes they represented were in proportion to the covertypes found in that quadrangle. Rectangular test fields were derived from these homogeneous areas and used for a second set of evaluation figures.

Systematic Photointerpretation. A third set of evaluation figures was calculated using photointerpretation for ground truth and systematically selected test fields 2 pixels by 2 pixels in size. The aircraft coverage was superimposed onto the grid on a base map with a Zoom Transfer Scope. Only the test fields which were homogeneous with respect to covertype, crown closure and species composition were used for the accuracy classification.

The classification was evaluated for two levels of vegetation detail: 1) generalized which incorporated water, coniferous, deciduous, mixed coniferous and deciduous, grassland, and sparsely vegetated and bare; and 2) the community level which included water, dense coniferous, sparse coniferous, coniferous/deciduous mix, deciduous/coniferous mix, aspen, oak, wet grassland, mesic grassland, dry grassland, and sparsely vegetated and rocky.

Due to the variability in spectral class descriptions, it was necessary to evaluate the test fields on each 7 1/2' quadrangle separately, and then merge the values by community or generalized vegetation level to

give an overall evaluation. The original set of calculations was done
at LARS using very narrowly defined community types to evaluate the
test fields. Only one or two spectral classes were assigned to each
community class. No provision was made to remove the bad data (bad scan
lines) from the data set. Bad data comprised up to 50% of a community
sample, and was automatically counted wrong in this evaluation.

The initial evaluation figures were greeted with some dismay by
both INSTAAR and U.S. Forest Serivice personnel. U.S. Forest Service
personnel using the logogramatic maps had qualitatively evaluated the
maps at about 90-95% accurate for generalized, and 85-90% for the
community level. A separate qualitative evaluation by the INSTAAR photo-
interpreter doing the spectral class descriptions (Section C.5) had
placed the figures about 5% lower. The gut level feelings of those
working with the classification were that the data were good, but accu-
racy figures of 40-60% doomed any attempts for the U.S. Forest Service
to actually use the data in planning efforts.

Several problems were contributing to the low accuracy figures.
One was the inclusion of bad data in the total data set. There was
no way to map bad scan lines from the aircraft coverage or in the field,
and yet the classification was penalized for calling them bad data. The
question here became whether the classification of LANDSAT MSS data was
being evaluated, or if the LANDSAT hardware was being evaluated. As
the evaluation of LANDSAT MSS data was the purpose of this project,
the decision was made to delete bad scan lines from further calculations.

Another problem, and probably the main one, deals with the assigning
of spectral classes to the community types which are to be evaluated.
For the original calculations each community type was very narrowly
defined, with at the most 3 spectral classes assigned to any one commu-
nity type. An examination of the spectral class descriptions in Appen-
dix A shows that some spectral classes incorporate two or even more cover-
types. If a spectral class includes meadow and aspen at 100% crown clo-
sure, to which community type should it be assigned? Another aspect
of this problem particularly concerns mix community types. While it is
possible to locate a one acre unit on the aircraft coverage when it has
been mapped on a 7 1/2' base map, it is not as feasible to actually map

a one acre unit on the aircraft coverage. This is mostly due to the
width of a line from a triple O rapidograph, which completely covers a
one acre area. Homogeneous mix forest is seldom found such that there is one
conifer, an aspen, a conifer, an aspen, in a pattern. Mix forest includes
small patches of aspen and conifer and patches of varying mix composi-
tion, giving the entire area the appearance of mix forest. Are scattered
pixels of pure conifer wrong in coniferous/deciduous mix? Are pixels of
pure aspen wrong in deciduous/coniferous mix? Are meadow or sparsely
vegetated areas wrong in areas of conifer which have less than 60%
crown closure of trees? Ecological experience, U.S. Forest Service
community type definitions, and the proposed uses for this classifica-
tion indicate that the answers to the above questions are "no".

Since the programs currently available at LARS are not designed
to handle admixures of covertypes, the further evaluation work had to
be done by hand. To reduce subjectivity on the part of the investiga-
tors, each community type was described and spectral classes were assigned
to each type. The community type descriptions are given in Table C.8.
An ecological discussion of community types found in the Southern San
Juan Mountains Planning Unit is given in Section A. Spectral class
assignments to community types were made separately for each quadrangle
due to the variability of covertypes correlating with each spectral
class from one quadrangle to the next. Even with a detailed description
of each community type there was a broad latitude as to which spectral
classes should be included in each community type. Two sets of spectral
classes were assigned to each community type for three quadrangles.
One is a broad interpretation of the description which allows for almost
every possible covertype that could be expected to occur in each commu-
nity type. The other is a moderate interpretation of the description
which gives spectral classes which could reasonably be expected to occur
in each cover type. For example: the broad interpretation included all
dense conifers, all mixes, and all dense deciduous covertypes in both
coniferous/deciduous mix and deciduous/coniferous mix. The moderate
interpretation includes only conifers and mix covertypes in coniferous/
deciduous mix, and only mix and deciduous covertypes for the deciduous/
coniferous community type.

After the spectral classes were assigned to community types, the

Table C.8. Community type descriptions used for the evaluation of the LANDSAT MSS classification.

Community Type	Description	Spectral Classes
Dense Conifer	This class is predominantly dense spruce-fir and douglas or white fir. Any dense ponderosa pine, bristlecone, or pinon-juniper (>70%) will probably show in this class. This includes scattered aspen, especially at higher altitudes where aspen was not yet leafed out on aircraft coverage. This covertype is also found in areas of topographic shadow, further making identification of scattered aspen difficult, especially in the underexposed corners of aerial photography.	This type should include all spectral classes relating to conifer >70%, including <30% aspen. This type may be classified as water in areas of intense topographic shadow.
Sparse Conifer	This type includes all species of sparse conifer from 20% to about 60%. Logged areas, stress sites, old fires, krummholz and ponderosa pine communities as well as most pinon-juniper appear as sparse conifer. This type is easily confused with other classes, especially coniferous/deciduous mix. Grass and/or slash is increasing the reflectance and giving the impression of a deciduous component when none is present. The possibility is that at higher elevations willow or aspen were not yet leafed out on the June, 1975 aircraft coverage.	This class should include all spectral classes relating to conifers <60%, dry meadow, or occasionally mesic tundra, and rocky grassland or bare rock. This class will probably also include riparian communities with 20-60% blue spruce and cottonwood <70%.
Coniferous/Deciduous Mix	This type incorporates the loosely defined mix communities that are predominantly conifer with oak or aspen. Due to the small scale photography and the physical impossibility of mapping areas of <5 acres, as well as the mottled composition of a mixed covertype, there will be sections which are pure conifer, pure aspen, and deciduous/coniferous mix. In areas of 70% density meadows may show sparse conifer, but these are probably edge effect. Test fields called coniferous/deciduous mix may actually have more aspen at higher elevations than designated as the aspen is not fully leafed out on the coverage.	This type should include all spectral classes relating to conifer >70%, and all mixes.

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Community Type	Description	Spectral Classes

Deciduous/Coniferous Mix

This category includes the vague group of mixes which are predominantly deciduous, usually aspen, but occasionally oak, with all coniferous types having a total crown closure >70%. Because of limitations of base maps, small scale photography, and field observations, this type will also include a few pure conifers (community category A), pure aspen (community category F), and all mixes. Sparse conifer and meadows may also show, but should not be included as they are probably edge effect and are not within the limits of this definition. Aspen in dry sites may have changed color in the September satellite data, and more conifer will show proportionally than is actually present.

Spectral classes are acceptable for the full range of pure aspen and all mixes >70% density.

Aspen

This type includes all pure aspen from about 60% with grass to 100%. This category may include <20% conifers. There may be problems with this class relating to the late leafing out at higher elevations, and early color turn in September showing in the satellite data. This type may include some coniferous mix. This category is being confused with meadow, especially in the Spectacle Lake quadrangle. Coniferous/deciduous mix is occasionally mapped in these test fields. A few of these may actually be right, but are more likely due to topographic shadow or edge effect.

All spectral classes relating to aspen >60% with grass, or even with oak, up to 100%, and deciduous/coniferous mix with <20% conifer are acceptable.

Oak

This covertype covers all oak greater than about 40% to 100% with grass. There may also be some aspen mixed in with the oak. There may even be a few scattered ponderosa pine but they should be less than 10%.

Spectral classes acceptable in this category include everything pertaining to oak with grass greater than 30 or 40%, or oak and aspen mix with grass. Meadow categories, especially dry, or dry and rocky grasslands are acceptable since this may cover up to 60% of the area. Less than 10% conifer and rocks are also acceptable. This type probably includes other miscellaneous deciduous species such as cottonwood or willow.

Community Type	Description	Spectral Classes
Wet and Mesic Grassland	This category includes meadow and grassland communities that are relatively wet throughout the growing season. The main problem encountered with test fields in this class seems to be that the meadows dried out more between June and September than anticipated. It is difficult to predict how dry a meadow will be three months later, especially when there are factors of irrigation, river flow, snow melt at higher altitudes, grazing pressures, and storm patterns. This class also includes riparian willow and probably some alpine willow and cottonwood.	Included in this category are all spectral classes relating to wet meadow with shrub (willow), wet meadow and mesic tundra. There seems to be a lot of sparse conifer in this class, but it doesn't really fit the confines of this definition.
Grassland	This category incorporates all grassland types ranging from relatively wet to pretty dry, but which have 80-100% herbaceous cover with very few rocks.	Spectral classes in this class include wet, mesic and dry grassland with little or no bare rock. In the Platoro and Bighorn quadrangles, mesic and dry rocky grasslands are acceptable.
Rocky Grassland – Sparsely Vegetated	This category covers sparsely vegetated areas with >50% bare rock. This grassland becomes very dry in late summer and fall. Included in here are exposed tundra and the dry flatlands in the eastern portion of the planning unit.	Spectral classes in this category include all those pertaining to dry, and dry rocky, sparsely vegetated covertypes. This may also include areas mapped as mesic in spring which actually dry out more by fall than expected.
Bare Rock	This category includes areas of bare rock and soil. Some areas mapped as bare in spring may appear vegetated by fall. Sparsely vegetated categories would be accepted, but not those with >50% herbaceous cover.	Spectral classes in this category are those incorporating bare or sparsely vegetated covertypes.

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Community Type	Description	Spectral Classes
Water	This type is all large bodies of water. To be accurately viewed as lakes, this type should incorporate an area of at least 3-5 acres in fall, and be on less than a 10% slope. Many shadow areas are mapped as water. These often are dense conifer or bare rock, or sparse conifer and bare rock on steep north facing slopes. These areas could be eliminated from the map by putting a slope steepness condition on the request. Water itself is probably under-represented on the tabloids, but the topographic shadow more than makes up for it.	Spectral classes relating to water are the only ones acceptable in this community category.

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homogeneous photointerpretation method of selecting test fields was selected for further work and calculations. This method was chosen for several reasons. The results from it are more consistent than the systematic photointerpretation method (see Table C.9) and it best represents the covertypes, and the proper proportions of each, that are found in the study area. When aircraft coverage is available for a study, this method is faster than either field work or systematic evaluation. Using aerial photography it is possible to cover the entire area of concern, while field work is dependent on area accessibility and the vagaries of the weather. Using a systematic photointerpretation method test fields are forced into a static grid and size.

The 25 spectral class printout was used for the hand evaluation. Each test field was located by the line and column coordinates which LARS had used for the first set of evaluation figures. The number of each spectral class in the test field was counted and recorded. Each test field had been assigned to a community type at the time it was selected from the aircraft coverage. The total number of pixels of each spectral class was tabulated for all test fields in each community type. The accuracy then was calculated by adding the pixels in acceptable spectral classes for the community type and dividing by the total number of pixels found in the test fields of that community type. Calculations were made using the broad interpretation for three intensive quadrangles, and the moderate interpretation for all six of the intensive quadrangles. All work was double checked by the person doing the counting, or by another of the INSTAAR team; and all calculations, performed on electronic hand calculators, were done at least twice. A comparison of the narrow, moderate, and broad interpretations for the Platoro quadrangle are shown in Table C.10.

A significant conclusion is that the three methods used for test field selection gave similar evaluation results for the vegetation classification of LANDSAT MSS data. The evaluation results derived from the three types of test field selection for the Chromo NE quadrangle are a good illustration. These data are based on the narrowly defined categories for the generalized vegetation level and for the community level. Test fields based on field data gave evaluation results for the generalized level of 64.3% correctly classified and for

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Table C.9. Comparison of different methods of test field selection.
These calculations were based on the narrowly defined
community descriptions. Figures are given for both the
generalized and community levels of evaluation.

Generalized

	homogenous photointerpretation	systematic photointerpretation	field grid
Test quadrangle			
Bighorn Peak	66.8	88.3	
Chama Peak SE	78.8	51.0	
Chromo NE	70.2	66.0	64.3
Platoro	74.7	51.7	56.0
Spectacle Lake	73.2	53.0	
Wolf Creek Pass NE	49.0	54.1	

Community

	homogenous photointerpretation	systematic photointerpretation	field grid
Bighorn Peak	57.2	74.1	
Chama Peak SE	54.0	34.9	
Chromo NE	45.4	46.9	41.0
Platoro	68.3	38.9	44.6
Spectacle Lake	55.9	43.9	
Wolf Creek Pass NE	33.0	40.5	

Table C.10. A comparison of the three different interpretations of community types for the Platoro quadrangle. Each set of figures had a different set of spectral classes assigned to each community type.

Community Type	Narrow	Moderate	Broad
dense conifer	83.4	91.0	92.3
sparse conifer	36.7	61.2	67.3
coniferous/deciduous mix	53.2	95.8	95.8
deciduous/coniferous mix			
aspen	84.2	94.1	94.1
oak			
wet and mesic grassland	61.7	72.6	72.6
grassland	52.6	63.2	70.5
sparsely vegetated	59.5	68.0	83.7
bare rock	43.4	81.9	81.9
water	100.0	100.0	100.0
all covertypes	69.0	82.7	85.7

the community level of 41.0%. Test fields based on a systematic grid
of 2 X 2 pixels using photointerpretation gave evaluation results
for the generalized level of 66.0% correctly classified and for the
community level of 46.9%. Test fields based on proportionate homo-
geneous areas using photointerpretation gave evaluation results for
the generalized level of 70.2% correctly classified and for the commu-
nity level of 45.4%.

Of greater importance than test field selection are the cover type
definitions (Table C.8). A thorough ecological knowledge of the vege-
tation of the area and how the data are to be used establishes the defi-
nitions and descriptions of the cover types. Only then can spectral-
informational classes be assigned to given cover types (Appendix A.2)
to evaluate the classification results. The moderate interpretation
which emphasizes the ecological aspects of the computer-aided analysis
of the cover type descriptions was parallel to that used by the U.S.
Forest Service.

The set of figures finally selected to represent the accuracy of
this classification are the moderate interpretation of the homogeneous
photointerpretation test fields. The figures were merged by covertype
for each quadrangle to come up with values for the entire study area.
The evaluation results for each quadrangle by covertype are in Appendix
B. The overall evaluation results for generalized and community level
combined are shown in Table C.11. The final calculations for the entire
study area show the generalized level of vegetation to be 84.4% accurate,
and the community level to be 79.8% accurate.

Several definite conclusions have emerged from the work on the
evaluation of this covertype classification:

1) An evaluation is a necessary part of a project if the pro-
   ducts are to be used in resource inventory or planning
   processes.

2) The test fields should not be selected from the training
   fields.

3) The test fields need to incorporate all covertypes, and the
   relative proportions of each, that have been included in
   the classification.

4) The method for selecting test fields is not as important as defining the covertypes for which the evaluation is done. This assumes that whatever test fields are used include all covertypes of interest in relative proportion.

5) When adequate aircraft coverage is available, the test fields selected by photointerpretation from areas of homogeneous covertype is the fastest and gives the most accurate reflection of the study area.

6) When aircraft coverage is not available, an evaluation can be made based on field data.

7) A systematic grid with requirements for mapping and recording in the field forces the observer to become acutely aware of the covertypes and the factors controlling their distribution. If the actual data is not a necessary part of the project, the observer should make an effort to become familiar with as much of the study area as possible.

8) The final evaluation figures should not be considered as "so many correctly classified out of 100 possible", as the ground truth is seldom if ever 100% correct.

Table C.11. Final evaluation figures for the six intensive quad-
rangles representing the entire study area. These
figures are for the homogenous photointerpretation
test fields using the moderate interpretation of
community types.

Community Level

Community Type	Overall Accuracy	% of Total Sample
dense conifer	85.6	17.2
sparse conifer	62.0	2.5
coniferous/deciduous mix	92.7	24.3
deciduous/coniferous mix	76.2	7.8
aspen	68.8	7.4
oak	51.5	2.1
wet and mesic grassland	74.2	13.0
grassland	76.8	14.5
sparsely vegetated	71.3	6.6
bare rock	65.6	3.1
water	92.8	1.5
overall - all community types	79.8	100.0

Generalized Level

coniferous	87.1	19.7
deciduous	69.6	9.5
mix	95.6	32.1
grassland	78.2	27.5
sparsely vegetated and bare rock	73.0	9.7
water	92.8	1.5
overall - all community types	84.4	100.0

SECTION D

TOPOGRAPHIC DATA UTILIZATION

P.E. Anuta, LARS   D. Adams, LARS

Digital registration of topographic data with LANDSAT and other
remote sensing data sources enables a wide variety of comparisons to
be made between land cover and topography. Slope steepness and slope
aspect can be computed from digital elevation data, providing additional
information about each pixel. The flexibility of a system which in-
corporates land cover and topographic parameters adds significantly
to the planning process used by the U.S. Forest Service. Resource
data overlays combining different features are necessary to make
management decisions and land allocations.

A key part of the study was to obtain and exploit digital topo-
graphic data. This section describes first the characteristics of
digital topographic data available from the Federal Government and
then explains the registration and slope and aspect computation
processes. Finally the processors for combining the results of
multispectral remote sensing data classification with topographic
data are explained and examples are presented of combined output
products.

D. 1. Topographic Data Details.

The Defense Mapping Agency, an agency of the Dept. of Defense (DMA),
has developed a system for digitizing topographic maps and has
recently digitized 1:250,000 scale maps for the continental United
States (Noma, 1974). These maps are manually digitized on table
coordinate digitizers and interpolated to a uniform grid using a
planar algorithm. This algorithm computes a linear function (plane)
which passes through the three points nearest to the grid point
desired and evaluates the function at the grid point. This is done
for each point in the digital output array. In this manner a uniform

grid of elevation values is obtained from the unequally spaced samples
from the contours. The digitizing increment is .254 mm in the x and
y directions on the 1:250,000 scale map and this corresponds to 64
meters on the ground. The grid cell size used in the digital data is
64 meters. Thus, the cell resolution is the same as the raw data
resolution. The topographic data is written in 16 bit words (15
bit plus sign) on tape and delivered to users. At LARS, the data is
reformatted and placed in a format which utilizes 8 bit words. The
quantization level of the original data is nominally 1 meter. In
order to fit the elevation range of the map into 8 bits (0-255) the
data must be rescaled. For the case of the Durango East quadrangle
(NJ13-7E) the elevations range from 1805 to 4344 meters. Thus the
LARS tape quantization is:

$$\frac{(4344-1805)}{256} = 9.9 \text{ meters.}$$

A significant quantization error is therefore introduced with respect
to the contour interval, which is 61 meters. However, percentagewise,
with reference to the range of 3539 meters, the 9.9 meter quantization
error is only 0.4%, which is assumed to be reasonable. The accuracy
of the original elevation points is not known, but since they were
interpolated from contours having an interval of 61 meters it can be
assumed that the error is no worse than that obtained in interpretation
of elevations from the original map. In a personal communication from
Mr. Donald Stuart of the DMA it was stated that "the topographic data
is no more or less accurate than similar data obtained by careful
scaling and interpretation of the map."

A format problem was encountered with this data in that the
rows of the topographic data were oriented north-south on the DMA
tapes and row direction in the LARSYS and most remote sensing systems
is east-west or across track of flight lines. Thus, a transposition
of the topographic data array on tape was required. The final topo-
graphic tape contained 1 channel of eight bit values in a 64 meter
grid for the entire Durango East quadrangle which covers a one degree
rectangle of latitude and longitude. In order to retrieve the true
elevation values from the eight bit words, the lower and upper limits
of elevation (1805 m and 4344 m in this case) are stored in full pre-

cision format on the LARSYS tape identification record and used to rescale the eight bit data to the original range. Therefore, the true elevations can be printed out by LARSYS, subject to the 0.4% quantization error.

The DMA topographic data was originally available from the agency itself; however, the responsibility for distributing the data has recently been transferred to the U.S. Geological Survey. The maps are digitized in 1 degree blocks for each 1° x 2° quadrangle. Thus two blocks are generated for each map and are denoted "east" and "west". The data can be ordered from:

U.S. Geological Survey
National Topographic Information Center
507 National Center
Reston, Virginia 22092

The data is available in either 800 or 1600 BPI tape density, oriented toward IBM 360 machines. Format information is supplied with the data. The cost is $15 per tape plus $6 for each block on the tape. The 800 BPI tapes hold 4 blocks (2 1:250,000 maps). Thus the cost for one tape containing two 1° x 2° quadrangles is $15 + (4 x $6) = $39.

D.2. Registration.

Precise digital registration of the topographic and LANDSAT data is necessary in order that the benefits of the digital topographic data be obtained. The normal procedure for image to image registration at LARS (Anuta, 1970) is to use a numerical correlation procedure to find control points in the images to be registered. For the registrations required here manual techniques were required due to the dissimilar nature of the data involved. The topographic data in general will not correlate with the LANDSAT data. Therefore, nominally, twelve matching points in the data sets to be registered were found visually using a digital image display system and computer line printer generated images. The x-y coordinates of these points were punched on cards and processed by a least squares bi-quadratic polynomial approximation program (Anuta, 1975) to define coefficients for use by the registration program. The registration algorithm used a nearest neighbor rule to define output points which

are required between existing input data points. Since the topographic grid spacing is 64 meters square and the LANDSAT reference grid is 57 by 79 meters, the registered topographic data will have position errors which range from zero to 32 meters which is an error characteristic of the nearest neighbor method.

The approach used for the data registrations for the Durango East quadrangle was to transform the topographic data to match the LANDSAT data which had previously been rotated to a north orientation using an approximate geometric correction procedure (Anuta, 1973). In future registrations, it is recommended that the LANDSAT data be precision corrected to a geographic coordinate grid so that the output products will accurately match standard maps. The resulting product is minimally a five channel tape having the four LANDSAT bands plus elevation as a fifth channel. Slope and aspect calculations can then be made, adding two to three additional channels.

D.3. Topographic Slope and Aspect Derivation.

The data analysis process and interpretation of results could benefit by the addition of slope steepness and slope aspect information if it could be made available on a pixel basis as additional registered channels on the data tape. This requirement was met by numerically differentiating the topographic data to produce an estimate of the gradient vector at each pixel location. The magnitude of the vector is then used to derive the slope angle and the direction is used as the aspect angle. The approximate gradient at line i and column j is computed as:

$$\vec{\nabla Z} = \vec{I} \ (z_{i-1,j} - z_{i+1,j}) + \vec{J} \ (z_{i,\ j-1} - z_{i,j+1})$$

where $\vec{\nabla Z}$ is the gradient vector

z_{ij} is the topographic elevation at i,j

i,j are line and column coordinates

$\vec{I}$ and $\vec{J}$ are line and column unit vectors

The slope angle is computed from the magnitude of gradient. The $|\vec{\nabla Z}|$ value is the vertical change in elevation over one unit of pixel distance; thus the slope is:

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$$s_{ij} = \tan^{-1}\left[\sqrt{\frac{(z_{i-1,\,j} - z_{i+1,j})^2 + (z_{i,j-1} - z_{i,j+1})^2}{2\Delta d}} \right]$$

where: s_{ij} is the slope angle at point i,j with $0 \le s \le 90$ degree.

Δd is the pixel spacing (equal line & column spacing assumed here). The aspect angle is derived from the vector direction of the gradient:

$$\alpha = \tan^{-1}\left[\frac{(z_{i-1,\,j} - z_{i+1,j})}{(z_{i,\,j-1} - z_{i,j+1})} \right] - 90° \quad \left| \begin{array}{l} \text{If } \alpha < -180° \\ \alpha = \alpha + 360° \end{array} \right]$$

where α is the direction of slope measured clockwise from north. Since only positive values from 0-255 can be represented on the eight bit format tapes the aspect angle is recorded on a range of zero to 180 in one channel and an additional channel is added which had only the values zero or one. If the slope is uphill to the east semicircle, the zero-one channel will have a value of zero and if uphill to the west semicircle it will be one. Thus, a pixel having a slope upward toward the east will have an angle value of 90° and a flag value of zero. In this case, the resolution of the slope and aspect angles is one degree. The aspect angle is also available as a continuous 0 to 360° variable scaled to 0 to 255.

The slope and aspect angle derivation was implemented in a program which adds the three angle channels to a data tape as three additional channels, assuming the last channel on the input tape was the topographic elevation channel. Example gray scale images were generated for an area centered near the Vallecito Reservoir from the Durango West quadrangle to illustrate the topographic channels. Figure D.1 contains an image from the LANDSAT MSS data and from the three topographic channels. The upper left image is LANDSAT data from Band 5 (.6-.7 micrometers), the upper right image is a gray scale representation of the elevation channel with low values having darker gray levels and high values having lighter gray levels. The gray resolution of the image is very limited, with only 10 levels, and the image does not satisfactorily illustrate the available information. There are actually 256 discrete elevation levels available and these are compressed to the 10 gray levels seen in the image. The lower left image contains a gray scale reproduction

DIGITAL REGISTRATION OF LANDSAT AND TOPOGRAPHIC DATA

LANDSAT MSS

ELEVATION

SLOPE

ASPECT

Figure D.1. Gray scale reproductions of LANDSAT, elevation, slope, and aspect data.

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of the slope angle channel. Bright areas represent steep slopes and dark areas are gentle slopes, with black being flat areas. The lower right image is a gray scale representation of the aspect data for the same area. Darker areas represent southerly facing slopes and lighter areas represent northerly facing slopes. Black areas are level areas.

D.4. Post-Classification Processing.

The registered LANDSAT and topographic data tape is an input to the data classification process which generates surface classification files using spectral data or a combination of spectral and topographic data in the classifier. The result of this phase is a LARSYS classification tape called the results or map tape. This tape has a specialized format which is not compatible with the multi-channel data tapes. A combination procedure was developed as part of the study to enable logical relationships to be computed between the classification of LANDSAT data and topographic data.

The first step in the post-classification processing procedure is to merge the classification and topographic data in a LARS data tape MIST (Multispectral Image Storage Tape) format which is byte oriented and reasonably easy to work with. The merged data tape then forms the master input to the segmenting and combination process.

The second step is a topographic segmentation process in which the elevation, slope and aspect data are divided into ranges specified by the user, and each range is identified by a code number. The output of this step is another MIST tape which can be considered the working MIST tape which will be used for making a variety of combination outputs. The segmentations of the topographic channels on this tape are expected to be relatively unchanging. The master MIST tape with the full range of the topographic variables on it must still be kept, since without it new segmentations could not be made.

The third and most user oriented step is the combination process in which ground cover classes from the LANDSAT classifications and topographic "classes" (range categories) are combined to produce specialized outputs. The program for this phase has a user oriented

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control language and can combine classification, elevation, slope, and aspect variables as defined on the input cards. The output from this program currently is in the LARSYS classification map format since that enables the LARSYS results display software to be used to produce line printer output, color photographic output and area tabulations. If an external user, such as the U.S. Forest Service, had a different system, this data could be used in a simpler format such as straight byte or MIST format.

D.5. Topographic Data Utilization System.

The flow of data through each of the steps will now be described with reference to a diagram to clarify the function of each element. Figure D.2 contains a data flow and functional block diagram for the process as it currently exists.

1. Topographic Data Registration

   Digital topographic data is acquired for the area covering the site of interest and registered to remote sensor data as previously described. The data can be from any source such as topographic maps which have been manually digitized and/or aircraft multispectral scanner data. In the present study, LANDSAT data and DMA topographic data were used. LARS has the capability to register any of these data and it is assumed at present that future preparation of such overlays will be done at LARS. Exportation of the LARS image registration and precision geometric correction capability is not feasible at this time.

2. Remote Sensing Data Classification

   LARSYS classification techniques are applied to the multi-spectral data on the master MIST tape which may contain several passes of LANDSAT data plus the topographic overlay channels. These are extensive procedures covered in other portions of this report and in many other LARS documents. This phase will not be discussed further here except to indicate that the output is a standard results tape with the classification decisions for each pixel considered. It is assumed that the LARSYS system produces the output tape. If other systems were used programs in the following steps would have to be changed.

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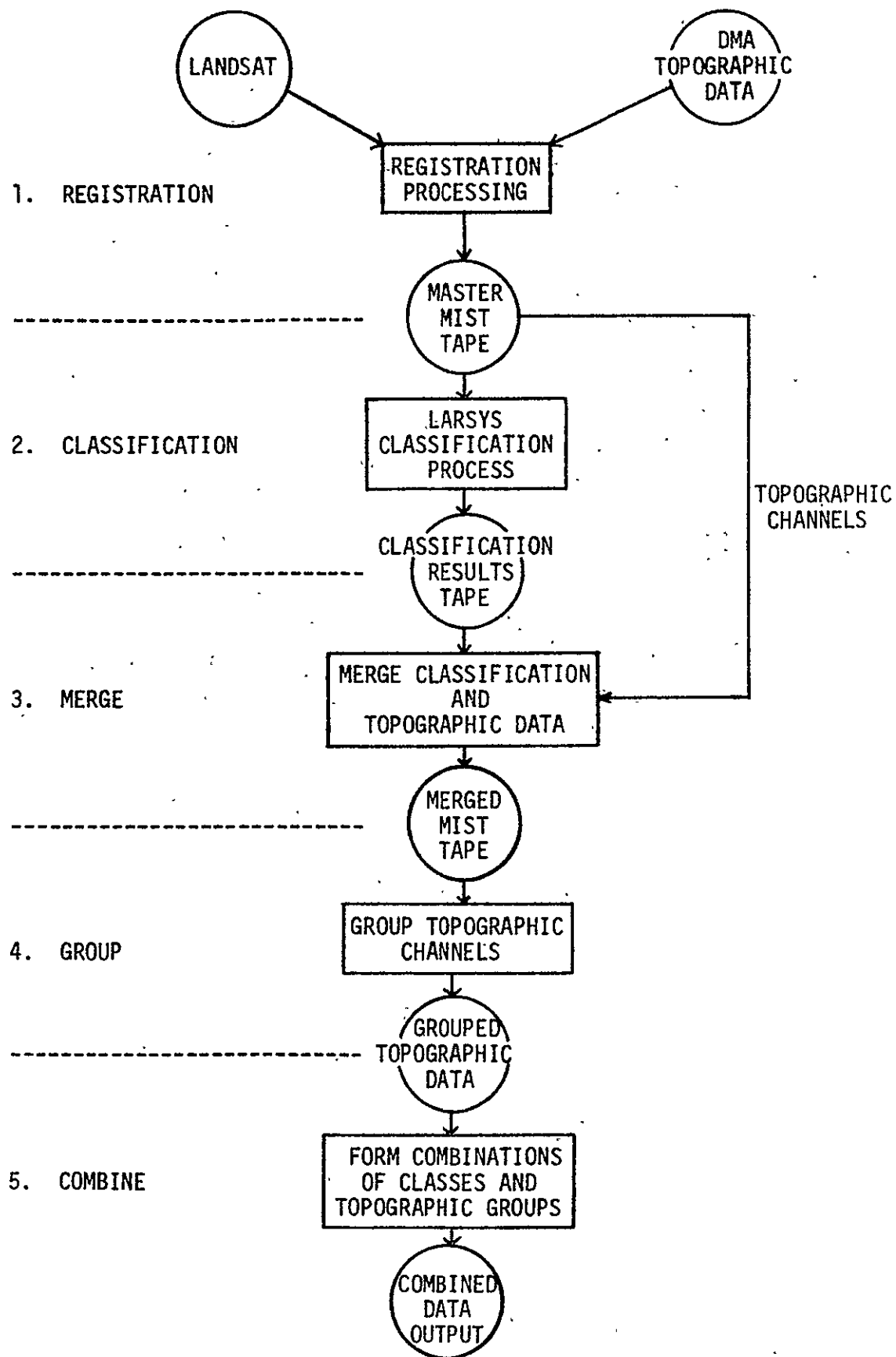
Figure D.2. Block diagram of topographic data utilization process.

3. Merging of Classification and Topographic Data

The results tape produced in Step 2 and the topographic channels from the master MIST tape are merged to form a four channel MIST tape containing the classification decisions for each pixel in channel 1, elevation in channel 2, slope in channel 3 and the aspect in channel 4. Although aspect is available on the master MIST tape in two forms, the continuous circle $0-360^{\circ}$ form is used for the combination functions. The merged MIST tape contains topographic variables in "continuous" form (i.e., true elevation, slope from 0 to 90°, etc.), and in a segmented form which is desired for use in the combination program. Thus a segmentation or grouping step follows.

4. Topographic Data Grouping

The function of this phase is to divide up the topographic variables into given ranges. For example elevations between 0 and 3000m, 3000 to 4000m, etc., slope 0 to 5%, 5 to 10% etc. These ranges are coded sequentially 1,2,3..., and written on an output tape in MIST format. The classification results derived from the multispectral data are copied unaltered to channel one of the output tape. The output is in the same MIST format as the input tape. This can be called the merged and grouped data tape.

5. Classification and Topographic Combinations

The final and most important step is the combination process, which combines the spectral classes of LANDSAT data classification with topographic groups. The program which does this has a form of control language which allows the user to form the relationships desired within the constraints of the topographic data groupings derived in Step 4. The output is in the LARSYS results tape format readable by the * PRINTRESULTS processor and *PHOTO display processor.

D.6. Examples of Use of Topographic Data.

The LANDSAT data used in the study was overlaid with topographic data covering the Durango East half quadrangle, covering a one by one degree area in latitude and longitude. The LANDSAT data from

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September 20, 1973 (Frame No. 1424-17132) were classified into 25
spectral classes and these were identified by relating to ground truth
(see Appendix A). The topographic data were grouped into the following
ranges:

1. Elevation (m)

Range	Code Number
Less than 2000	1
2000 to 2100	2
2100 to 2200	3
2200 to 2300	4
2300 to 2400	5
2400 to 2500	6
2500 to 2600	7
2600 to 2700	8
2700 to 2800	9
2800 to 2900	10
2900 to 3000	11
3000 to 3100	12
3100 to 3200	13
3200 to 3300	14
3300 to 3400	15
3400 to 3500	16
3500 to 3600	17
3600 to 3700	18
3700 to 3800	19
3800 to 3900	20
3900 to 4000	21
4000 to 4100	22
4100 to 4200	23
Greater than 4200	24

2. Slope (The slope variable is stored in integer degree values
from 0 to 90 on the master MIST tape.)

Range	Code Number
0° to 1°	1
1° to 3°	2
3° to 5°	3

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Range	Code Number
5° to 10°	4
10° to 15°	5
15° to 22.5°	6
22.5° to 50°	7
50° to 90°	8

3. Aspect (The aspect input variable varies from 0 to 360° in 255 steps. An angle of 0° means the slope is north facing).

Angle Range	Directional Name	Code Number
0° to 15°	North	1
15° to 45°	North-Northeast	2
45° to 75°	East-Northeast	3
75° to 105°	East	4
105° to 135°	East-Southeast	5
135° to 165°	South-Southeast	6
165° to 195°	South	7
195° to 225°	South-Southeast	8
225° to 255°	West-Southwest	9
255° to 285°	West	10
285° to 315°	West-Northwest	11
315° to 345°	North-Northwest	12
345° to 360°	North	13

Several example outputs are presented here to illustrate the functioning of the grouping (Step 4) and combining processes (Step 5). Both tabular and image display formats can be generated by use of the *PRINTRESULTS processor in LARSYS. However, since the results tape is a single channel format the topographic and combination evaluations must be done individually, i.e., a separate results tape file must be generated for elevation, slope, aspect and each combination individually.

The first four illustrations are tabulations by 1:24,000 quadrangle for the three topographic variables and for the Big Game Winter Range combination. Table D.1 contains the percentage of the total samples in each quadrangle in each of the 100 meter elevation intervals. Table D.2 is the percentage of the total in each slope range, and

Table D.3 contains the same breakdown for aspect in the 13 direction segments. Table D.4 contains a classification breakdown for Big Game Winter Range for each quadrangle. These tables illustrate the advantages of the digital topographic data for obtaining area classifications automatically and accurately with no manual interpretations.

The topographic variables are illustrated by coded results display maps for elevation, slope and aspect for two quadrangles: Platoro and Chromo NE. The tape file containing each of the three variables in grouped form was printed out with alphanumeric symbols representing the various data intervals. Figure D.3 contains the elevation map for the Platoro quadrangle and Figure D.4 is the elevation map for Chromo NE. Figures D.5 and D.6 contain the slope variable in the 13 intervals coded with alphanumerics and printed in map format for the Platoro and Chromo NE quadrangles. Figures D.7 and D.8 are similar presentations for the aspect variables for the same quadrangles. These outputs illustrate use of the variables individually in the same way as spectral classifications have been traditionally processed.

The major thrust of this part of the project is illustrated where combinations of given ranges of several variables are made. The first example of a combination requested by the U.S. Forest Service is big game winter range in which the informational class "grassland" (spectral classes G,H,I,P,Q,S,T,U,V) was combined with slopes less than 30°, with the aspect variable restricted to south-southeast, south, and south-southwest, and for elevations between 7500 and 9000 feet. This combination of variable ranges and classes is presented in Figure D.9 for the Chromo NE quadrangle. This type of output is easily obtained from the grouped MIST tape by specifying the desired combinations on the input cards for the combination program.

Figures D.10, D.11, and D.12 show spruce/fir, aspen, and coniferous-deciduous mix on slopes of less than 30%, 30-45%, and greater than 45% for the Platoro quadrangle. This information was requested by the Rio Grande National Forest to aid in planning the Hillman Lake timber sale. These examples illustrate the new capabilities available from registered topographic data and the combination processing software.

The remaining problem is one of technology transfer. As stated earlier, the registration of topographic data to remote sensor data is a non-documented LARS reformatting type of operation and is not readily exported. The tape formats, control cards, and program listings for the combination program are included in Appendix D. The processing of future data through this phase is recommended as a LARS supplied operation which can be charged for in manpower, materials, and computer time. A per quadrangle rate could be established; however, since the topographic data is obtained in one degree blocks it would be most advisable to overlay this magnitude of area then cut the result into quadrangles if desired, since only one overlay job is involved rather than sixteen.

Table D.1. Percentage tabulation of elevation for each quadrangle. Figures are given for 500 meter increments.

QUADRANGLE	PERCENTAGE OF SAMPLES CLASSIFIED INTO:			
	2,000-2,500m	2,500-3,000m	3,000-3,500m	3,500-4,000m
Wolf NW	17.4	46.2	29.5	6.9
Wolf NE	5.8	41.4	51.1	1.7
Elwood	0.0	10.0	67.5	22.4
Summitville	0.0	3.1	61.3	35.6
Jasper	0.0	17.4	54.0	28.6
Greenie Mt.	0.1	65.8	34.1	0.0
Fulcher	78.0	22.0	0.1	0.0
Wolf SW	76.5	23.3	0.2	0.0
Wolf SE	0.8	45.7	48.6	4.9
Summit Pk.	0.0	12.5	46.6	40.9
Platoro	0.0	1.2	68.6	30.2
Red Mt.	0.0	13.1	82.0	4.9
Terrace Res.	0.1	77.0	23.0	0.0
Centro	76.1	23.9	0.0	0.0
Chromo NW	99.3	0.7	0.0	0.0
Chromo NE	33.4	51.7	14.9	0.1
Chama NW	0.3	39.1	50.2	10.4
Chama NE.	0.0	3.5	57.6	39.0
Spectacle L.	0.0	34.0	64.8	1.2
La Jara	0.0	80.5	19.5	0.0
Vicente C.	21.2	78.8	0.0	0.0
Chromo SW	89.9	10.1	0.0	0.0
Chromo SE	69.0	30.5	0.5	0.0
Chama SW	27.3	53.2	18.6	0.9
Chama SE	6.6	32.7	47.8	12.9
Cumbres	7.0	12.3	71.4	9.4
Oiser	7.1	39.8	53.1	0.0
Fox Creek	9.9	90.0	0.1	0.0

Table D.2. Percentage tabulation of slope for each quadrangle. Slope categories are given in percent of slope.

QUADRANGLE	PERCENT OF SAMPLES CLASSIFIED INTO:							
	0-1%	1-3%	3-5%	5-10%	10-15%	15-22.5%	22.5-50%	50-90%
Wolf NW	10.6	4.7	6.9	23.5	20.6	21.7	11.7	0.2
Wolf NE	9.9	4.6	8.0	25.3	24.2	19.8	8.2	0.0
Elwood	11.6	5.2	8.6	23.8	20.9	20.9	9.0	0.0
Summitville	9.2	8.0	12.5	29.0	20.9	15.8	4.6	0.0
Jasper	9.7	4.9	9.0	24.5	24.2	19.0	8.4	0.2
Greenie Mt.	18.7	7.6	12.5	25.1	18.0	13.4	4.7	0.0
Fulcher	59.4	12.3	17.5	7.0	2.6	1.1	0.1	0.0
Wolf SW	26.9	13.5	18.9	25.2	10.3	4.5	0.8	0.0
Wolf SE	5.4	4.4	7.2	22.1	23.4	24.3	13.2	0.1
Summit Pk.	7.2	3.1	6.0	17.9	24.3	27.4	14.0	0.1
Platoro	15.2	5.9	9.0	21.9	20.7	18.7	8.5	0.1
Red Mtn.	19.0	12.2	15.4	27.1	13.9	9.9	2.6	0.0
Terrace	32.0	15.0	21.5	19.3	7.4	3.8	0.9	0.0
Centro	70.0	10.1	14.8	3.0	1.4	0.6	0.1	0.0
Chromo NW	35.0	10.9	17.3	19.4	10.4	5.8	1.2	0.0
Chromo NE	13.7	13.6	17.4	31.5	13.8	8.4	1.6	0.0
Chama NW	9.2	4.6	6.3	18.2	20.5	25.5	15.6	0.1
Chama NE	17.6	8.4	11.6	20.7	15.8	16.1	9.6	0.2
Spectacle L.	27.9	8.6	12.1	17.6	12.5	14.0	7.2	0.1

Table D.2. (Cont.)

QUADRANGLE   PERCENT OF SAMPLES CLASSIFIED INTO:

	0-1%	1-3%	3-5%	5-10%	10-15%	15-22.5%	22.5-50%	50-90%
La Jara	39.3	13.7	17.4	16.2	6.9	4.6	1.9	0.1
Vicente C.	47.5	16.0	20.6	8.7	4.1	2.4	0.8	0.0
Chromo SW	37.2	13.5	19.8	17.8	6.8	4.0	0.9	0.0
Chromo SE	29.2	14.4	19.6	23.0	8.4	4.5	1.0	0.0
Chama SW	18.0	9.1	14.3	29.6	13.9	10.9	4.1	0.1
Chama SE	15.5	6.7	9.5	27.9	19.4	15.0	5.9	0.0
Cumbres	30.1	11.0	13.8	23.9	11.5	7.7	1.9	0.0
Olser	28.4	14.6	15.3	22.3	10.2	7.1	2.0	0.0
Fox Ck.	39.2	15.2	19.0	14.9	6.5	4.2	1.0	0.0

Table D.3.   Percentage tabulation of aspect for each quadrangle. Aspect categories are given as compass directions.

QUADRANGLE	PERCENTAGE OF SAMPLES CLASSIFIED INTO:					
	NNE	ENE	E	ESE	SSE	S
Wolf NW	6.9	11.8	13.4	9.7	3.7	0.5
Wolf NE	8.0	8.2	7.3	6.3	4.6	1.3
Elwood	2.7	5.0	6.7	8.9	7.3	1.4
Summitville	7.4	11.4	8.4	8.3	5.5	1.0
Jasper	8.5	9.2	7.8	10.2	7.9	1.3
Greenie Mt.	4.9	9.8	10.5	9.9	6.6	1.1
Fulcher	0.9	4.8	15.6	11.9	1.0	0.0
Wolf SW	4.6	6.4	3.0	3.4	2.0	0.2
Wolf SE	6.3	6.3	6.1	8.0	4.9	1.4
Summit Pk.	7.8	8.7	6.4	6.0	5.2	1.8
Platoro	5.5	9.3	7.7	8.5	7.8	1.5
Red Mtn.	4.1	10.7	13.3	10.6	4.6	0.4
Terrace	1.5	9.6	19.2	11.0	6.0	0.3
Centro	0.4	4.3	12.3	7.1	0.9	0.1
Chromo NW	3.6	5.6	3.7	2.8	2.3	0.6
Chromo NE	5.0	5.3	2.8	2.8	2.3	0.2
Chama NW	7.8	11.5	8.0	5.6	3.3	1.1
Chama NE	5.4	8.3	8.7	8.3	5.3	1.3
Spectacle L.	2.9	7.0	8.0	14.2	7.7	0.8

Table D.3. (Cont.)

QUADRANGLE		PERCENTAGE OF SAMPLES CLASSIFIED INTO:				
	SSW	WSW	W	WNW	NNW	N
Wolf NW	2.3	4.9	8.0	13.1	6.0	19.8
Wolf NE	7.4	9.5	6.3	8.4	6.8	26.0
Elwood	6.2	8.6	11.4	12.1	5.2	24.4
Summitville	7.6	8.8	5.6	5.7	4.9	25.5
Jasper	4.4	4.2	4.6	7.2	7.6	27.1
Greenie Mt.	5.5	4.0	2.1	3.7	5.7	36.2
Fulcher	0.1	0.1	0.0	0.2	0.3	65.1
Wolf SW	4.3	11.6	10.5	8.3	4.0	41.7
Wolf SE	8.2	12.2	10.3	9.6	6.8	20.0
Summit Pk.	7.7	10.3	7.5	8.9	7.4	22.3
Platoro	5.1	7.4	5.3	7.0	5.8	29.0
Red Mtn.	2.8	5.7	7.9	7.1	3.2	29.5
Terrace	0.8	1.5	2.9	3.9	1.7	41.6
Centro	0.1	0.1	0.4	0.6	0.2	73.6
Chromo NW	4.7	8.2	6.4	7.0	3.9	51.0
Chromo NE	7.7	17.8	13.8	8.2	4.5	29.5
Chama NW	4.4	9.7	15.2	9.6	4.6	19.3
Chama NE	5.2	7.1	6.5	5.9	4.4	33.7
Spectacle L.	1.8	1.8	2.9	6.8	4.6	41.5

Table D.3. (Cont.)

QUADRANGLE	PERCENTAGE OF SAMPLES CLASSIFIED INTO:					
	NNE	ENE	E	ESE	SSE	S
La Jara C.	2.2	5.3	11.8	12.9	4.4	0.2
Vicente C.	1.1	4.1	13.1	12.7	2.2	0.2
Chromo SW	1.8	6.3	7.5	4.6	2.2	0.3
Chromo SE	3.5	5.2	2.6	1.9	1.6	0.4
Chama SW	3.7	5.7	5.5	3.8	2.2	0.3
Chama SE	5.2	9.5	10.1	9.0	5.0	0.3
Cumbres	4.8	10.1	10.3	9.2	5.0	0.3
Oiser	2.7	8.5	13.4	15.0	5.4	0.4
Fox Ck.	2.6	6.3	12.8	13.0	3.2	0.2

Table D.3. (Cont.)

QUADRANGLE PERCENTAGE OF SAMPLES CLASSIFIED INTO:

	SSW	WSW	W	WNW	NNW	N
La Jara C.	1.0	1.8	2.1	3.3	3.1	51.8
Vicente C.	1.8	4.2	1.3	0.3	0.6	58.5
Chromo SW	2.9	7.6	9.3	6.5	1.6	49.5
Chromo SE	2.2	5.7	9.0	13.6	7.2	47.1
Chama SW	3.3	10.3	14.8	13.4	6.2	30.9
Chama SE	0.9	3.7	9.1	13.0	8.2	26.0
Cumbres	1.0	2.5	4.5	4.0	3.7	44.6
Oiser	2.2	4.2	2.6	5.4	2.4	37.7
Fox Ck.	1.2	2.1	2.7	2.8	2.2	50.9

Table D.4.   Percentage tabulation of vegetation classified as Big Game
Winter Range, (B.G.W.R.) Water, and Other for each
quadrangle.

QUADRANGLE	PERCENTAGE OF SAMPLES CLASSIFIED INTO:		
	OTHER	B.G.W.R.	WATER
Wolf NW	98.7	1.0	0.3
Wolf NE	98.4	1.3	0.3
Elwood	99.7	0.0	0.3
Summitville	99.8	0.0	0.2
Jasper	99.5	0.2	0.3
Greenie Mt.	97.8	2.2	0.0
Fulcher	98.1	1.9	0.0
Wolf SW	99.2	0.8	0.0
Wolf SE	99.1	0.6	0.3
Summit Pk.	98.7	0.1	1.2
Platoro	97.8	0.0	2.2
Red Mtn.	99.8	0.0	0.2
Terrace	97.2	1.9	0.9
Centro	98.9	1.1	0.0
Chromo NW	98.2	1.6	0.2
Chromo NE	98.9	0.8	0.3
Chama NW	98.4	0.2	1.4
Chama NE	99.4	0.0	0.6
Spectacle L.	99.0	0.7	0.2
La Jara C.	98.5	1.4	0.0
Vicente C.	96.9	3.1	0.0
Chromo SW	99.1	0.9	0.0
Chromo SE	97.8	2.1	0.0
Chama SW	98.9	0.8	0.2
Chama SE	99.7	0.2	0.1
Cumbres	99.7	0.0	0.2
Oiser	98.7	1.3	0.0
Fox Ck.	96.2	3.8	0.0

Figure D.3. Elevation in 100 meter intervals in map format for the Platoro quadrangle.

COLORADO
MIKE FLEMING

LABORATORY FOR APPLICATIONS OF REMOTE SENSING
PURDUE UNIVERSITY

ELEVATION - PLATORO RESERVOIR QUADRANGLE

CLASSIFICATION STUDY 607166374
RUN NUMBER............. 73069304
FLIGHT LINE... 142417132   COL
DATA TAPE/FILE NUMBER. 28967. 1
REFORMATTING DATE. FEB 6,1976

CLASSIFIED   MAR 11,1976
DATE DATA TAKEN... SEPT 20,1973
TIME DATA TAKEN..... 1013 HOURS
PLATFORM ALTITUDE...3062000 FEET
GROUND HEADING..... 180 DEGREES

CLASSIFICATION TAPE/FILE NUMBER ... 375/ 3

CHANNELS USED

CHANNEL 5   SPECTRAL BAND 0.0 TO 0.0 MICROMETERS   CALIBRATION CODE = 4   C0 = 2056.   C1 = 4307.

CLASSES

SYMBOL	CLASS	SYMBOL	CLASS
M	UNDER 2.		3.1-3.2
2	2.0-2.1	.	3.2-3.3
	2.1-2.2	-	3.3-3.4
.	2.2-2.3	+	3.4-3.5
-	2.3-2.4	/	3.5-3.6
+	2.4-2.5	X	3.6-3.7
/	2.5-2.6	I	3.7-3.8
X	2.6-2.7	0	3.8-3.9
I	2.7-2.8	M	3.9-4.0
0	2.8-2.9	4	4.0-4.1
M	2.9-3.0		4.1-4.2
3	3.0-3.1	.	OVER 4.2

Figure D.4. Elevation in 100 meter intervals in map format for the Chromo NE quadrangle.
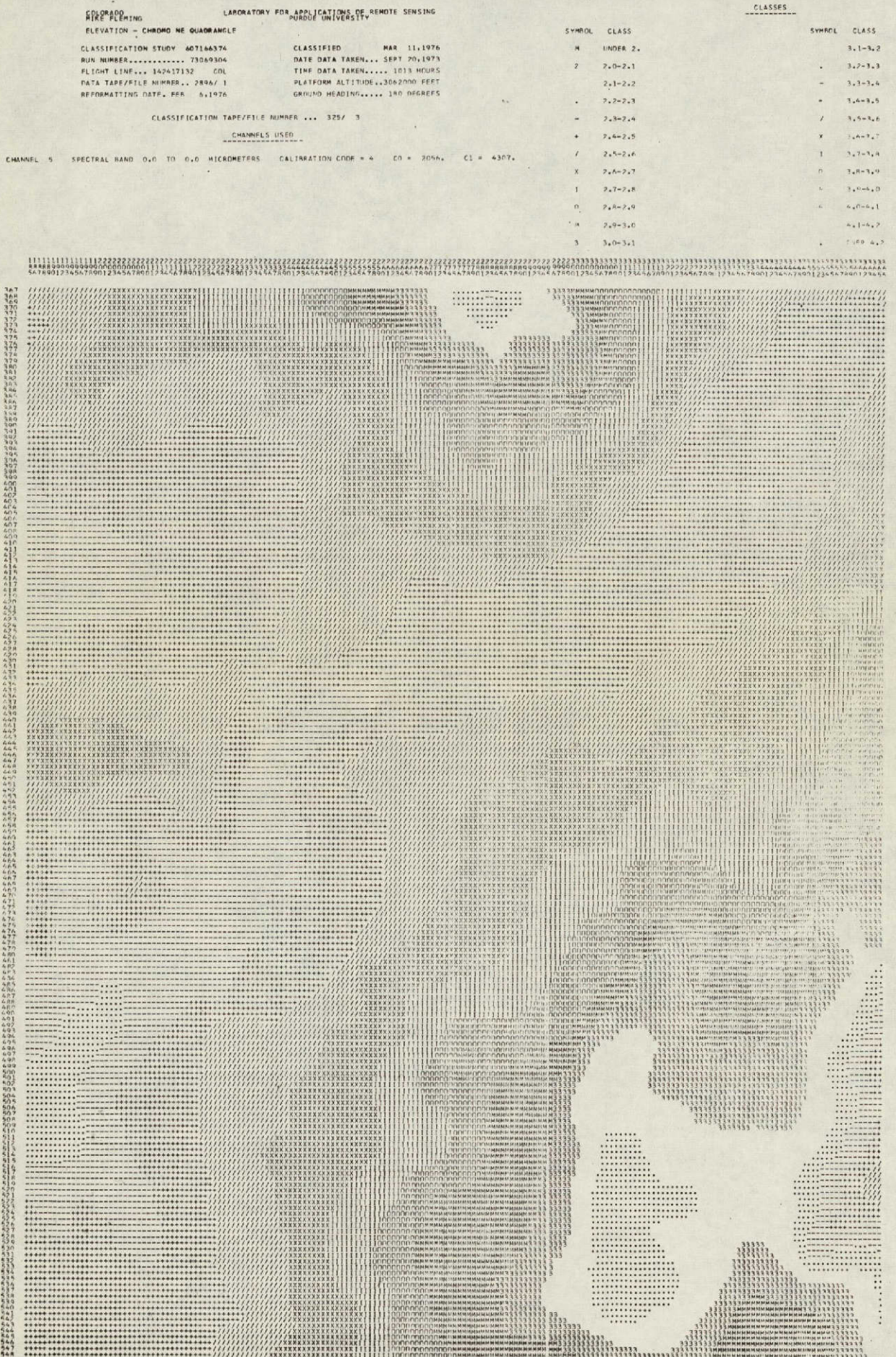
Figure D.5. Slope in 8 intervals for the Platoro quadrangle.

Figure D. 6. Slope in 8 intervals for the Chromo NE quadrangle.

Figure D.7. Aspect in the 12 thirty degree direction segments for the Platoro quadrangle.

Figure D.8. Aspect in the 12 thirty degree direction segments for the Chromo NE quadrangle.

Figure D.9. Big game winter range category for the Chromo NE
quadrangle.
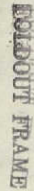
Figure D.10. Spruce/Fir class categorized by slope for the Platoro quadrangle.

NUMBER OF POINTS DISPLAYED IS   20202

NUMBER OF POINTS DISPLAYED IS   12922

10.823 SECONDS.   (LARSMN)

Figure D.11. Aspen class categorized by slope for the Platoro quadrangle.

```
        CLASSIFICATION STUDY  616455069        CLASSIFIED         JUNE 12,1976
        RUN NUMBER............ 76000003        DATE DATA TAKEN... 8RM  0.19 0
        FLIGHT LINE... 142417132    COL        TIME DATA TAKEN.....      HOURS
        DATA TAPE/FILE NUMBER.. 331/ 2         PLATFORM ALTITUDE..     0 FEET
        REFORMATTING DATE. MAR  22,1976        GROUND HEADING.....   0 DEGREES

                    CLASSIFICATION TAPE/FILE NUMBER ...   53/ 1

                                 CHANNELS USED
                                 -------------

    CHANNEL  1    SPECTRAL BAND  0.0  TO  0.0  MICROMETERS    CALIBRATION CODE = 1    CO = 0.0
    CHANNEL  2    SPECTRAL BAND  0.0  TO  0.0  MICROMETERS    CALIBRATION CODE = 1    CO = 0.0
    CHANNEL  3    SPECTRAL BAND  0.0  TO  0.0  MICROMETERS    CALIBRATION CODE = 1    CO = 0.0
    CHANNEL  4    SPECTRAL BAND  0.0  TO  0.0  MICROMETERS    CALIBRATION CODE = 1    CO = 0.0
```

CLASSES

SYMBOL	CLASS	WEIGHT		SYMBOL	CLASS	WEIGHT
W	WATER	1.000		O	ASPEN-S	1.000
	SF-L	1.000			MIX-L	1.000
	SF-M	1.000			MIX-M	1.000
	SF-S	1.000			MIX-S	1.000
=	ASPEN-L	1.000			-OTHER-	1.000
/	ASPEN-M	1.000				

NUMBER OF POINTS DISPLAYED IS   20202

NUMBER OF POINTS DISPLAYED IS   12922

10.571 SECONDS.   (LARSMN)

Figure D.12. Mixed forest (coniferous/deciduous) class categorized by
slope for the Platoro quadrangle.

SECTION E

GEOMORPHIC MAPPING

S. Agard, INSTAAR   S. Loranger, INSTAAR

The U.S. Forest Service, Region 2, uses the Land Systems Inventory, as developed by Wertz and Arnold (1972), for long range land use planning. The land system is based on a hierarchical breakdown of landforms from a broad, regional level into smaller, more homogenous and discrete units (Table E.1). Under this system, the San Juan Mountains are a section of the Southern Rocky Mountain Province, and are divided further into subsections of glaciated mountain land and fluvial mountain land. Ideally, each subsection would then have unique landtype associations, which would be composed of unique landtypes, and so forth. At the onset of this project, the Rio Grande National Forest had developed the Land Systems Inventory in the Southern San Juan Mountains to the level of landtype association (Brock, 1974).

The Ecological Land Unit (ELU) and the Ecological Water Unit (EWU) are currently the basis of the land use planning process in the Southern San Juan Mountains Planning Unit. Both the ELU and EWU are partly based on landform units (landtype associations). INSTAAR has evaluated LANDSAT MSS data for landform mapping in general and within the system used by the Forest Service. This has resulted in the development of manual analysis techniques applicable to current planning efforts.

INSTAAR's investigation progressed in two distinct phases. The initial work emphasized the U.S. Forest Service land systems classification and focused on the system at the landtype association level already in use and on defining the mapping categories at the landtype level, the next level of greater detail. The landtype mapping categories would provide a data base for some land use decisions which could not be made with the landtype associations. Categories at the landtype level were defined and mapped using low-level aerial photographs. LANDSAT was then evaluated as a mapping tool for both landtypes and landtype associations.

TABLE E.1.

LAND SYSTEMS INVENTORY
(after Wertz and Arnold, 1972)

NAME	BASIS FOR DELINEATION	EXAMPLE	SIZE RANGE	PRINCIPAL APPLICATION
Province	Basic elements Structure, lithology, climate First order stratification	Service Cascade Colored Plateau Basin and Range Province	1000^S of square kilometers	Nationwide or broad required data summary
Section	Basic elements Structure, lithology, climate Second order stratification	Uinta Basin Grand Canyon	100^S to 1000^S sq. kilometers	Broad regional summary. Basic geologic climatic vegetation data for design of individual resource inventories.
Subsection	Basic elements Structure, lithology, climate Third order stratification	South Park Southern San Juan Mountains San Luis Valley	10^S to 100^S square kilometers	Strategic management direction, broad areas planning.
Landtype Association	Manifest elements Soils, landform, biosphere First order stratification	Smooth Mtn. Land High Hills Uneven Mtn. Land Fluvial Bottomlands	2.5 to 25^S square kilometers	Summary of resource information and resource allocation.
Landtype	Manifest elements Soils, landform, biosphere Second order stratification	Ridge Sideslope Landslide Alluvial Fan	.25 to 2.5 square kilometers	Comprehensive planning, resource plans, development standards, local zoning.
Landtype Phase	Manifest elements Soils, landform, biosphere Third order stratification	Not defined	2.5 to 25 hectares	Project development plans.

LAND SYSTEMS INVENTORY

NAME	BASIS FOR DELINEATION	EXAMPLE	SIZE RANGE	PRINCIPAL APPLICATION
Site	Represents integration of all environmental elements. Site not delineated on maps.	Timbersale Mine drain Campground	.4 hectares or less	Provides precise understanding of ecosystems. Sampling will be defined for broader units, for research and for detailed on site project action programs. Adapted from Wertz and Arnold, (1972).

This initial evaluation was undertaken by an interpreter trained in physical geography.

Because of limitations inherent in the landtype and landtype association classifications, the second phase of INSTAAR's evaluation focused on LANDSAT MSS data as a tool for geomorphic studies. This did not necessarily stay within the context of the Land Systems Inventory. Analysis techniques developed emphasize manual manipulation of standard products readily available to U.S. Forest Service personnel. This part of the evaluation was undertaken by a second interpreter trained in geology and geomorphology.

E.1. Geomorphic History.

The Southern San Juan Mountains as they exist today result from the erosion of a broad domal uplift by running water and alpine glaciers. Flat-lying or gently-dipping Tertiary lava flows, ash-flow tuffs, and volcaniclastic rocks dominate the range. Pre-Cambrian crystalline rocks are exposed locally in New Mexico while Mesozoic sandstones and shales crop out mainly along the western flank of the mountains in Colorado. The complex and diversified Quaternary history which produced the deep canyons and rugged mountain peaks is summarized in Table E.2. The effect of this recent history on the landform development will be discussed in subsequent sections.

E.2. Land Systems Inventory.

E.2.1. Landtype association level.

Analysis of LANDSAT. The landtype associations (Table E.3) as defined by U.S. Forest Service personnel to meet regional planning needs are based on general slope percent ranges and local relief. Because LANDSAT MSS imagery at this latitude has a 33% overlap between adjacent frames, approximately 60% of the planning unit is covered in stereo. This provides a good model with sufficient detail for determining slope and local relief differences of small areas to produce landtype association maps.

Four LANDSAT frames were analyzed in this phase of the investigation, two from September 20 and 21, 1973 (1424-17132 and 1425-17190) and two from January 29 and 30, 1973 (1190-17145 and 1191-17204). At the

TABLE E.2.

GENERALIZED QUATERNARY HISTORY OF THE SAN JUAN MOUNTAINS
(after Atwood and Mather, 1932; Richmond, 1954; Mather, 1957)

AGE	EVENT	DESCRIPTION OF EVENT	RESULTING FEATURES AT PRESENT
Recent	Post-glacial erosion	Stream erosion, mass movements, and small local cirque glaciers modify the landscape remaining after the Wisconsin glaciations.	Rock glaciers, talus, small moraines, ravines in high country; landslides, debris flows, alluvial fans, incised streams throughout.
Late Wisconsin	Late Wisconsin Glacial State	Widespread glaciation fills every major valley with glacial ice.	Prominent terminal moraines in major valleys, lateral moraines high on valley walls, broad outwash plains.
	Interglacial Interval	Retreat of glaciers and slight renewal of uplift rejuvenates stream erosion.	Valleys deepened tens of meters in places.
Early Wisconsin	Durango Glacial Stage	Glaciers fill valleys and extend to mountain margins	Till and outwash on rock benched tens to hundreds of meters above present valley floors.
	Canyon Cycle of erosion	Renewed uplift of 610 meters in the center of the range to 100 meters at margins rejuvenates stream erosion.	Steep walled canyons cut 100 to 600 meters below valley floors of Florida cycle.
Pre-Wisconsin	Deposition of Florida Gravel	Overloaded master streams from melting of glaciers deposits bouldery gravels onto adjacent lowlands	High gravel caps over sandstones and shales in foothills and lowlands.

TABLE E.2.

GENERALIZED QUATERNARY HISTORY OF THE SAN JUAN MOUNTAINS (continued)
(after Atwood and Mather, 1932; Richmond, 1954; Mather, 1975)

AGE	EVENT	DESCRIPTION OF EVENT	RESULTING FEATURES AT PRESENT
Pre-Wisconsin (cont.)	Cerro Glacial Stage	Glaciers fill valleys and spread out as piedmont glaciers onto adjacent lowlands	Till remnants on interfluves and valley slopes high above present valley floors.
	Florida Cycle of Erosion	Broad domal uplift results in 610 to 760 meters of stream downcutting to form broadly U-shaped valleys.	Benches or shoulders high on existing valley walls.
Late Tertiary	Peneplain Cycle of Erosion	Widespread erosion of Tertiary volcanic upland forms surface of low relief known as the San Jaun Peneplain.	Flat-topped or gently-sloping summits of some high peaks.

TABLE E.3.

LANDTYPE ASSOCIATION

Code	Name	Definition
01	Bottom Lands	More than 80% of an area gently sloping and local relief variation ranges from 0-100 feet. Characterized by alluvial deposits. Slope rarely exceed 15%.
05	Rolling Uplands	50-80% of an area gently sloping, local relief variation ranges from 300-1000 feet and more than 50% of gentle slope is on upland.
13	Smooth Low Hills	20-50% of an area gently sloping and local relief variation ranges from 100-300 feet.
14	Smooth Mountain Lands	20-50% of an area gently sloping and local relief variation ranges from 300-500 feet.
19	High Hills	Less than 20% of an area gently sloping and local relief variation ranges from 500-1000 feet.
20	Uneven Mountain Lands	Less than 20% of an area gently sloping and local relief variation ranges from 1000-3000 feet.
22	Canyon-Scarp Lands	Extremely steep (75% plus) cliffs and rims, dominated by rock outcrops and colluvial slopes.
23	Glacial Depositional	Undulating to hilly landforms resulting from glacial deposition. Moraines, tills and outwashes typify the landscape.
24	Rock Outcrops	Exposures of bare rock greater than 80%.
25	Landslide Depositional	Areas of downward sliding or falling of relatively dry mass of earth, rock, or mixture of the two which have become loosened from a hillside by moisture, snow or man.

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onset of this project, these winter frames provided the clearest and
sharpest model of the planning unit due to snow enhancement of topo-
graphy. For most of the planning unit, the snow cover was light, and
almost absent from south-facing slopes, although snow was heavier at
higher elevations and somewhat less uniform due to wind deposition.
Band 5 of the LANDSAT frames provided the greatest tonal contrast.

The stereo images were viewed over a light table with a Zeiss
7X mirror stereoscope to provide the detail needed to map geomorphic
features. For the synoptic view, 3X magnification was utilized. A
zoom transfer scope was used to transfer the information to the Durango
2° base map.

Macro-dissection, which is a function of land slope regimes and
elevation ranges, was the basis for delineation of landtype associations.
The interpreter perceived a typical area and drew a boundary such that
the area within the boundary appeared to be distinct from and more
homogenous than the surrounding region. Unfortunately, the actual
landscape does not express changes as succinctly as the defined
mapping categories.

The interpreter found most landtype associations to be easily
delineated. Three relatively large landslides were also mapped.
Although their location was known prior to mapping, the hummocky sur-
face and lack of well-defined drainage enabled the delineation to be
made from LANDSAT. Large avalanche tracks were recognized with the
LANDSAT stereo model of the September frames. Rock outcrops were
difficult to recognize due to the close spectral resemblance to alpine
grasslands.

Comparative evaluation. As an independent evaluation of the landtype
association classification and the analysis method, a second inter-
preter attempted to duplicate the results of the above mapping effort.
Additional LANDSAT MSS imagery of improved quality and a stereoscope
with variable magnification were available during the second phase
of the project. However, for comparison, the same LANDSAT frames and
equipment of the previous analysis were used and the evaluation done in
approximately the same amount of time. Delineation of landtype associa-
tions were based upon U.S. Forest Service definitions alone (Table E.3)

without prior knowledge of where specific geomorphic features were located.

Comparisons were made among the two maps generated from LANDSAT images and the U.S. Forest Service landtype association map. The results (Figure E.1.) indicate a wide disparity among the three interpretations. Local relief is the key criterion for separating most of the categories, yet the relative relief that the interpreter "sees" may not be correctly calibrated to the actual amount of relief. Using a topographic map in conjunction with the LANDSAT frames may help to calibrate the interpreter's sight. However, there is also the problem of what is meant by local relief as used in the definitions. This could mean the amount of relief the landtype associations impart to the entire area, or it could relate to dissection relief within the landtype association boundaries. Local relief can be measured over any aerial extent, from major drainage to high peaks, or from small tributaries to the top of the interfluve. Nowhere in the U.S. Forest Service descriptions has this been clarified.

Other differences between the interpretations reflect problems with the classification and definitions. Glacial depositional and bare rock were not mapped by either INSTAAR interpreter primarily because these categories are not strictly topographic. Areas of bare rock were mapped as uneven mountain land, high hills, or canyon scarps depending on location and relief. On the basis of slope and local relief, landslides can occur in any one of several landtype associations. Between the two INSTAAR interpretations, smooth mountain lands (#14) and landslide depositional (#25) were often interchanged. Both INSTAAR interpreters included landslide areas mapped by the U.S. Forest Service in other categories. Landslides can be discerned from other landtype associations on LANDSAT, but they are not separable from other mapping categories as defined when using only the basis of slope and relief.

Several similarities can be noted among the three interpretations in spite of the many differences. Bottomlands and canyon-scarplands were recognized with consistency by all three interpreters, but mapped to somewhat different extents. However, grasslands, gentle lowlands and toeslope areas may have been incorrectly identified as bottomland. Some canyon-scarplands were mapped far into tributary canyons rather

Figure E.1. A comparison of the landtype association maps
derived by the U.S. Forest Service, Region 2, and two
separate INSTAAR interpreters.

    a. U.S. Forest Service, Region 2
    b. INSTAAR interpreter 1
    c. INSTAAR interpreter 2

Key for landtype association maps:
(refer to Table E.3 for landtype descriptions)

Code	Name
01	Bottom lands
05	Rolling uplands
13	Smooth low hills
14	Smooth mountain lands
19	High hills
20	Uneven mountain lands
22	Canyon-scarp lands
23	Glacial depositional
24	Rock outcrops
25	Landslide depositional

A. LANDTYPE ASSOCIATIONS—FOREST SERVICE INTERPRETATION
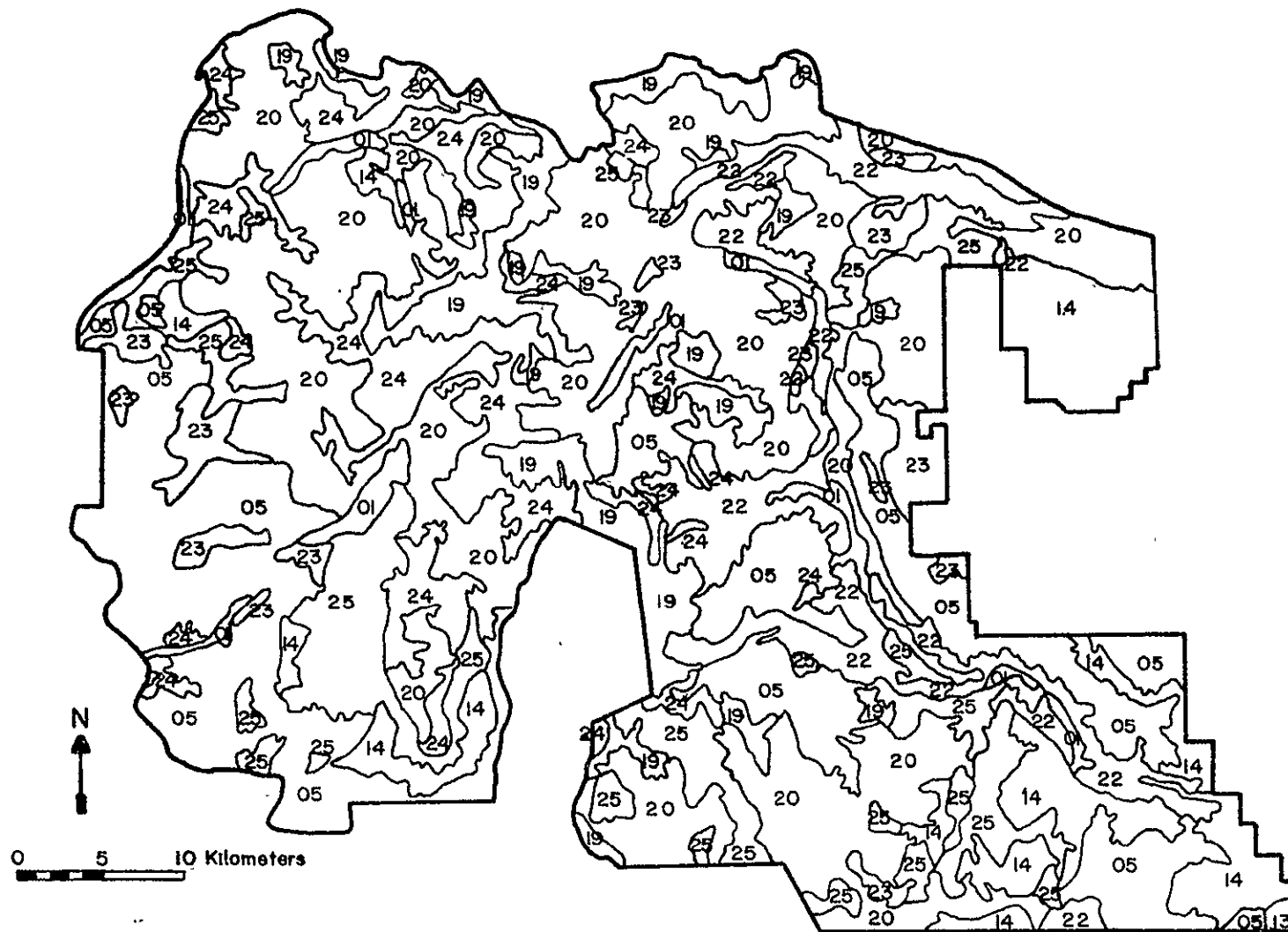
N

0   5   10 Kilometers

B. LANDTYPE ASSOCIATIONS—INSTAAR INTERPRETATION I

LIMIT OF STEREO COVERAGE

N

0   5   10 Kilometers

C. LANDTYPE ASSOCIATIONS—INSTAAR INTERPRETATION 2

129

N

0   5.   10 Kilometers

LIMIT OF STEREO COVERAGE
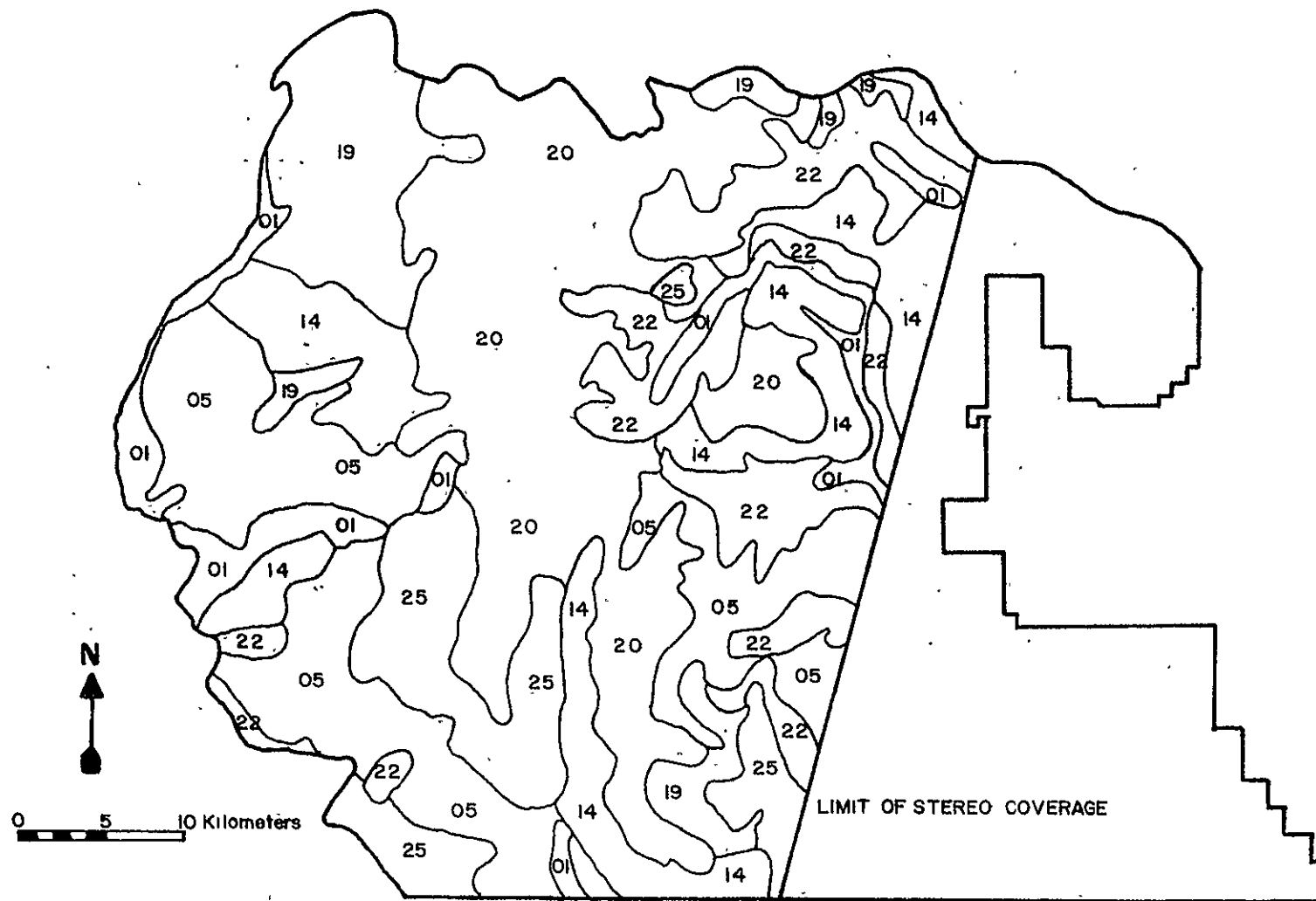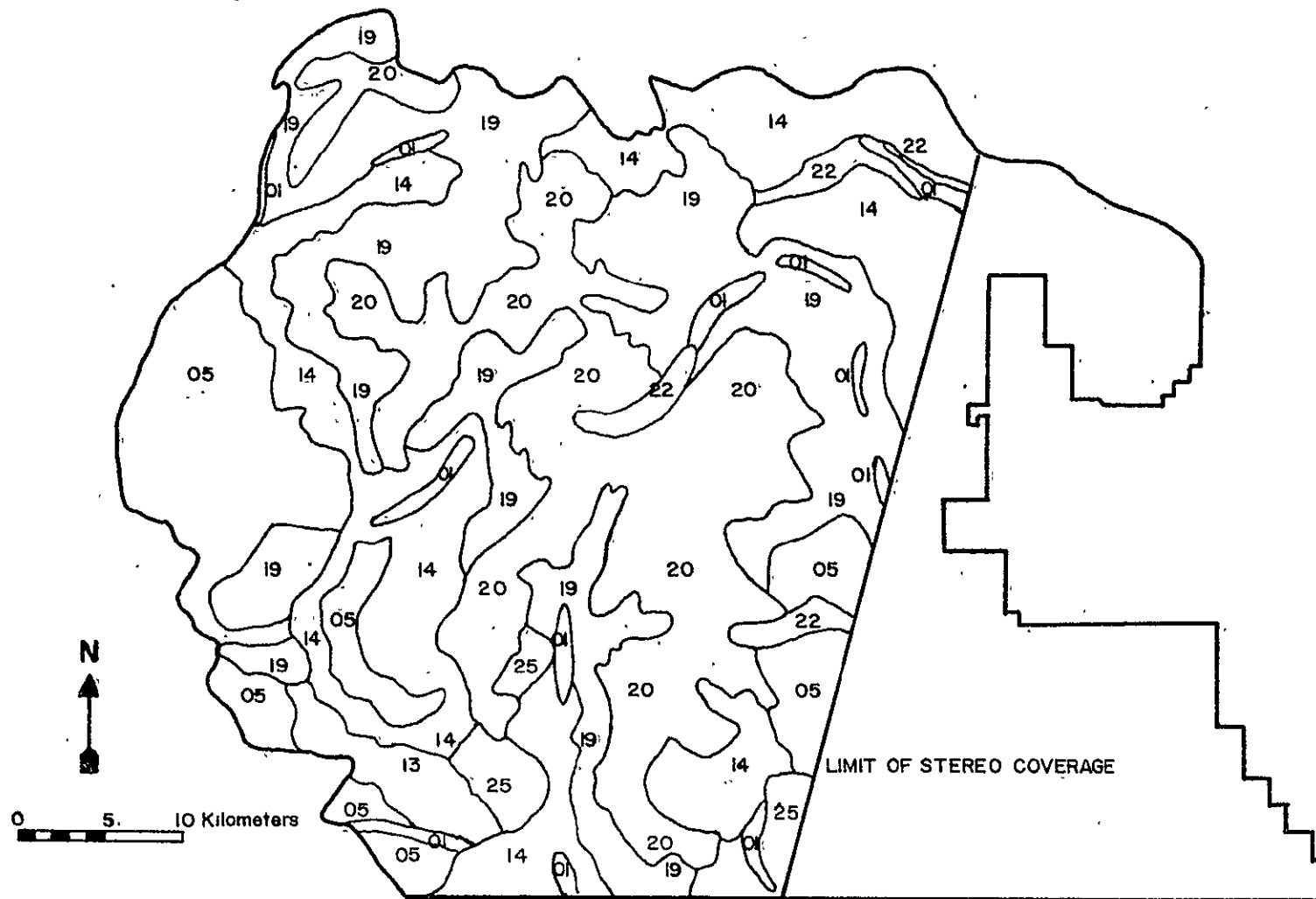
than just along major drainages. Here again, the definitions need
to be more specific. In other areas, boundaries on the three maps
tended to coincide, but the areas were assigned to different categories.
This disparity may relate to the different ways the interpreters per-
ceive local relief.

Both INSTAAR interpreters followed the same method, yet, the
resulting maps show a notable lack of detail relative to the U.S.
Forest Service map. This may reflect possible shortcomings of the
LANDSAT data, lack of ground familiarity on the part of the inter-
preters, shortcomings of the classification, insufficient definitions,
or a combination of these. The U.S. Forest Service map is not
necessarily more accurate as it was derived from the knowledge and
subjective judgments of many different U.S. Forest Service personnel.
The boundaries reflect a compromise among the widely varying opinions
within the three forest units rather than a systematic evaluation of
the data. It should also be noted that while the two INSTAAR maps
are quite dissimilar, the same method was used. This suggests that
the classification and definitions need some reworking. The problems
are further discussed in a later section.

Alternate analysis methods. Future mapping efforts could utilize
geometric pattern recognition of Department of Defense Mapping Agency
(DODMA) topographic tapes overlaid on LANDSAT computer compatible
tapes (see Section D). An analysis system can be designed to delineate
landtype associations on the basis of slope classes and land relief.
The categories which can be integrated into a dichotomous recognition
key are: bottom lands (01), rolling uplands (05), smooth low hills
(13), smooth mountain lands (14), high hills (19), uneven mountain
land (20), and canyon scarp (22). The three miscellaneous categories,
glacial depositional (23), rock land (24) and landslide depositional
(25), cannot be classified with the others because they can occur with
great irregularity and are not defined on the basis of topographic ex-
pression. Rockland can be delineated on the basis of spectral pattern
by computer-aided analysis techniques (Hoffer, et al., 1973). Thus,
only landslides and glacial deposits remain undetectable within the
automated framework.

With a gentle slope being defined as less than 20 percent, a

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dichotomous key is presented. The key has two distinct levels, the
percentage of a land area with gently sloping topography, and
the amount of land relief present. Specific combinations of these two
topographic expressions characterize eight of the eleven landtype
association categories. In the case of canyon scarp (22) an additional
requirement is necessary in areas having greater than 75 percent slope.

Level I: (percentage of area having gentle slope)	$\geq$80%	80-50%	50-20%	$\geq$20%			
						75% slope	
Level II: (land relief)	0-100'	100-300'	300-500'	500-1000'		1000-3000'	
Landtype Association (by code)	01	13	05 14	05	19	20	22
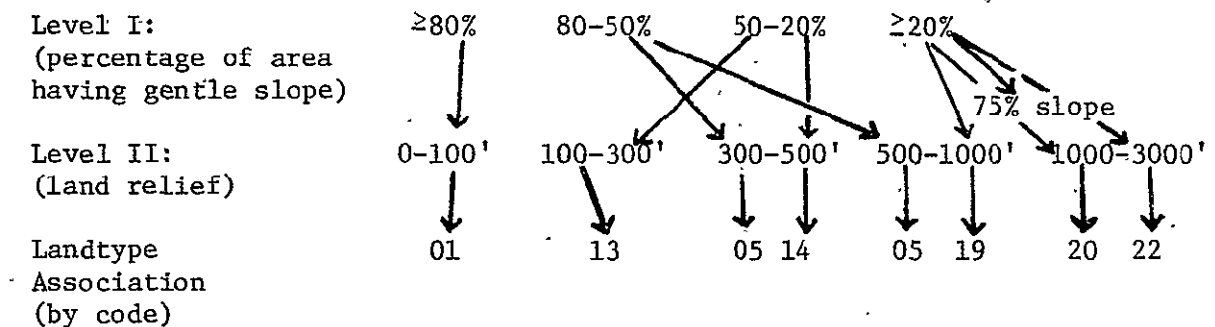
Not all possible combinations are found in the flow diagram. The
incorporated combinations are found in the planning unit and theoreti-
cally characterize all of the land. This remains to be tested within
the planning unit. For application to other areas, the dichotomous
system can be reworked to fit the particular landscape. This may
lead to a different set of combinations. This dichotomous system of
landtype association delineation is presented for future geometric
pattern recognition algorithms. However, minimal human interaction
can be incorporated to make this system feasible and practical with
present technology. The method utilizes the DODMA tapes, corrected
and displayed at 1:250,000. First, a 20% slope map is produced and
an interpreter can draw in the gentle slope classes, $\geq$80%, 80-50%,
50-20%, and $\geq$20%. An alternate method is to have the computer print
out a gentle slope class map and the interpretation is then not
necessary. Second, a land relief map is produced and an interpreter
can draw in the local relief classes, 0-100', 100-300', 300-500',
500-1000', and 1000-3000'. Again, an alternate method would be to
have the computer print out a local relief class map. The final stage
is to overlay the gentle slope map and local relief map and delineate
the landtype associations as defined by the dichotomous key.

With present technology, the manual overlay method would initially
be more time consuming than the present method. However, it has the
potential for more accuracy, paves the way for greater advances
in the automated delineation methods, and is applicable for those areas
where other tools, e.g., 7½' relief maps, are not available. The
present method utilizes a combination of aerial survey and interpretation
of 1:250,000 topographic maps, and takes approximately one man-week to
delineate landtype association for a planning unit size area (Brock,
personal communication). The new method presented above has not been
tested, and additional work is necessary to determine its validity.

E.2.2. Landtype level.

Before any landtype level mapping could be attempted, the mapping
categories had to be characterized and defined (Table E.4.) (Loranger,
1976). Aerial photographs were utilized in developing and characterizing
landtypes. Maps derived from these were field checked and served as
ground truth for comparison with other remote sensing products. With
the definitions thus developed, a variety of remote sensing tools were
evaluated, including air photos, SKYLAB, LANDSAT images, and products
derived from computer enhancement of LANDSAT data. U.S. Forest Service
black and white aerial photography (1956-1957 , scale 1:15,840) of the
entire planning unit is available. NASA underflight coverage is
available for the planning unit. A cursory examination of SKYLAB photo-
graphy showed that most landtypes can be adequately mapped, but not
at the detail afforded by larger scale photography. SKYLAB photography,
which is at a scale of 1:3,000,000 and in 70mm format was not analyzed
in great detail because of the limited availability for most land
areas.

LANDSAT analysis. LANDSAT black and white computer-enhanced products were
analyzed at the landtype level. A stereo pair was produced from two
LANDSAT MSS frames (1424-17132 and 1425-17190) on the digital display
unit at LARS. The data was geometrically corrected and displayed in
Bands 4, 5, and 7. False color images at 1:1 and 1:4 pixel displays
were produced by triple exposing with filters on color slide film. The
landtype mapping was accomplished on color print enlargements from the

Table E.4. Landtype Definitions (after Loranger, 1976).

Ridge	A destructional denudational form which is a narrow elongated crest of a hill or mountain.
Gentle Upland	A remnant of a structural surface which is a broad and nearly level upland area.
Sideslope	A constructional denudational form which occupies the undifferentiated inclined portions of mountain land, found below the local interfluve and above the fluvial bottomlands. A sideslope is composed of colluvium or colluvial-mantelled bedrock.
Toeslope	A constructional denudational form which is the depositional zone at the base of a hillslope and transitional to lowlands. It is distinguished from sideslope by a discrete change in slope gradient.
Bench	A destructional fluvial-denudational form which is long and narrow, gently inclined and built from constructional fluvial processes.
Floodplain	A constructional fluvial form which is adjacent to a river channel and inundated during annual high-water periods.
Alluvium	A constructional fluvial form which is composed of sand, gravel, cobbles or other transported material. Alluvium includes glacial outwash, or stratified drift that is stream built from glacial meltwater.
Alluvial Fan	A cone-shaped constructional fluvial-denudational form resulting from a tributary of high declivity running into the valley of a stream with less declivity. Alluvial fans include debris fans, or cone-shaped constructional denudational forms.
Landslide	Any constructional denudational form which displays evidence or a history of perceptible unit downward movement of a portion of the land surface.
Till	Any constructional glacial form.
Bare Rock	A miscellaneous landtype which occurs under all geologic formation processes and consists of any surface with more than 90% bare rock.
Alpine	A miscellaneous landtype which is the land surface above the absolute tree limit.

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color slides (scale 1:297,000). One 7½ minute quadrangle was mapped (Summit Peak).

Although prints have less resolution than comparable transparencies, several landtype features can be mapped accurately from false color imagery of this type. These are large ridges, gentle upland, sideslope, alluvium, extensive landslide, bare rock and alpine. The areal extent of the mappable features is within acceptable limits, however, the boundaries appear generalized due to edge effects between spectral classes. The landtype features not discernable with the above data format are small ridges, toeslopes, benches, floodplains, alluvial fans, small landslides, and till. Better stereo resolution is necessary to delineate these smaller landtype features. An independent evaluation of black and white stereo pairs in all four bands produced from the digital display unit was attempted. The information content with respect to landtype analysis was the same in all bands. Band 5 provided the best resolution, due to tonal contrast. The mapping detail which is possible from black and white stereo pairs is less than that of the false color stereo pairs explained previously. For this reason, no final maps were produced from these products. With the addition of more grey scale classes (30) and better photographic methods from the digital display unit the following landtypes possibly could be delineated from the LANDSAT system: large ridges, flat, sideslope, large landslide, fluvial bottomlands (collectively includes bench, floodplain, alluvium, and alluvial fan), bare rock and alpine tundra.

E.3. Comparison of Time Involvement.

A comparison of time involvement for mapping at the landtype association level and landtype level was made. The methods used by the Forest Service are based on black and white aerial photography and familiarity with the area through long-term field observation. The methods employed by INSTAAR involve the use of LANDSAT frames, computer enhanced display products from LANDSAT MSS data, and minimal field observation.

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Landtype Association Level Map for Planning Unit   (283,500 hectares)

<table>
<tr><td>INSTAAR</td><td>FOREST SERVICE</td></tr>
<tr><td>(LANDSAT Frame)</td><td>(Aerial Photography)</td></tr>
<tr><td>8 hrs</td><td>40 hrs.</td></tr>
</table>

Landtype Level Map of 7½' USGS Quadrangle.

<table>
<tr><td></td><td>INSTAAR</td><td>FOREST SERVICE</td></tr>
<tr><td></td><td>(Computer Enhanced
Product)</td><td>(Aerial Photography)</td></tr>
<tr><td>Initial
Observation</td><td>6 hrs.</td><td>3 hrs.</td></tr>
<tr><td>Actual
Mapping</td><td>3½ hrs.</td><td>3.6-4.4 hrs.</td></tr>
</table>

Landtype Level Characterization for Entire Planning Unit.

<table>
<tr><td>INSTAAR</td><td>FOREST SERVICE</td></tr>
<tr><td>4 months</td><td>never done</td></tr>
</table>

Includes:

development of landtypes	-1 mo.
acquisition and orientation to aerial photos	-50 hrs.
air photo interpretation	-25 hrs.
transfer to Hurd photos	-33 hrs.
field checking	-12 days
field data acquisition	-12 days
final maps	-48 hrs.
data collection	-72 hrs.
program into computer	-18 hrs.
computer analyst time	-40 hrs.
final tabulation and interpretation	-18 hrs.
write-up	-8 days/ 65 days total.

E.4. INSTAAR Evaluation of Land Systems Inventory.

In order for any system of landtype analysis to be useful and
operational from one area to another, the classifi·ation and description
of the landtypes must be clearly defined, and reproducible by dif-
ferent interpreters. During the second phase of this project, several
problems with the Southern San Juan Mountains system became evident,
both from a theoretical standpoint (i.e., the guidelines of Wertz and
Arnold, 1972), and from a practical standpoint (i.e., utility and
reproducibility).

Within the context of the Land Systems Inventory, each subsection
should have unique landtype associations which should be composed of
unique landtypes. The landtype associations (Table E.3) are mostly
topographic entities which can occur in both glaciated and fluvial
mountain lands. The landtypes (Table E.4) are not subdivisions of
the landtype association, but rather are independent subdivisions of
the entire planning unit. For example, sideslopes will be found in
smooth low hills, smooth mountain lands, high hills, and several
others. Thus, a sideslope is not a more homogeneous and discrete unit
of a landtype association but a completely different unit based on a
different set of parameters. The landtypes crosscut the landtype
associations which in turn crosscut the subsections instead of being
subdivisions of the higher units.

The basis of both the landtype associations and landtypes is not
consistent within either classification. The inconsistency creates
problems in identification of the units and in interpretation for land
use planning decisions. For example, the basis for most of the landtype
associations is topographic in nature, i.e., slope and local relief ·
(Table E.2). Glacial depositional and landslide depositional are genetic
classes and will overlap many if not all of the categories. Glacial
depositional features, described as "hilly to undulating" and typified
by "moraines, tills, and outwashes", could easily be mapped as rolling
uplands or bottomland, or mountain land depending on the age of
glaciation. Landslides will be concentrated along outcrops of unstable
geologic formations, such as the Mancos Shale, but can also be found
within any topographic regime. Rock outcrops are included as part of
the description of canyon-scarplands but are also defined separately.

Base geologic maps can be used if available. But there are inconsistencies as to the selection of genetic features to be incorporated in the classification.

Similar inconsistencies occur in the present landtype level. The entire planning unit can be mapped as ridge, sideslope, toeslope or bottomland. However, some small features are arbitrarily subdivided out of these units, and are given relatively more importance by being mapped separately. Alluvial fans are small scale toeslope features; floodplains and benches are small scale bottomland features. The detail in mapping these features is inconsistent with the lack of detail in units such as sideslope. Alpine is a vegetation descriptor, not a landform. Alluvium and till are not landforms, but deposits which occur in floodplains, benches, and alluvial fans, or moraines. It is inconsistencies such as these which make the system difficult to understand and interpret.

Ideally, any system should be based on the key parameters for the specific land use decisions. In the Southern San Juan Mountains, each landtype association supposedly reflects six essential characteristics which the Forest Service will consider when allocating activities, uses, and resources. The essential characteristics are average precipitation, elevation, range, slope (average and range), relative productivity, mass movement potential, and erosion hazard. . When landtypes are combined with two vegetation parameters, cover type and productivity, these form the Ecological Land Units which serve as the base data for planning. Unfortunately, these characteristics do not really define the landtype associations but merely describe them in a general way after they have been mapped. For example, half of the landtype associations are described by a slope range of 10% to 60%, and six of the ten have an average slope of about 45%. Mass movement potential is variable within each landtype association category depending on slope, and doesn't really define those categories. The characteristics of both landslide depositional and glacial depositional are nearly identical except for origin. The landtypes themselves, which are such an integral part of the ELU's do not accurately reflect the essential characteristics. After ELU's are defined and mapped, each area must still be examined in detail before management decisions can be made.

The final landtype classifications in the Southern San Juan Mountains

are a collection of the subjective judgements of many different Forest Service personnel. Each individual has a "gut feeling" about the nature of every area being mapped and how that area may re ct to different land uses. The Forest Service knows that certain areas are naturally unsuited for timber harvest. But why? What are the parameters that make an area suitable or unsuitable for a particular land use? Until these parameters are identified, the process documented, and the results demonstrated to be reproducible, the application of landtype classification to the planning process will be open to question. Because the limiting parameters for each use or resource have not yet been identified, and because the landtype associations do not reflect a systematic grouping of these parameters, the land use decisions will be based on subjectivity. The point here is that defensible management decisions should be based on a systematic evaluation of the limiting parameters for each land use and good base data derived specifically for these parameters.

E.5. LANDSAT As A Tool for Geomorphic Studies.

Because of the limitations of the Forest Service landtype and landtype association classifications discussed in the previous section, INSTAAR's continued evaluation of LANDSAT MSS data focused on LANDSAT as a tool for geomorphic studies in general. Features analyzed during this phase of the project often relate to specific aspects of the Forest Service Land Systems Inventory but were not restricted to the confines of the system itself. Although methods were developed and evaluated using specific geomorphic features, they can be readily applied by Forest Service personnel to other fields of interest within their planning structure.

LANDSAT MSS data were evaluated for the mappability of the following geomorphic features: 1) landslides, 2) glacial deposits, 3) bottomland features including floodplains and alluvial fans, and 4) drainage patterns (both as an indicator of the underlying geology and for possible hydrologic inventories). Standard products rather than computer enhanced products were emphasized because they are

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readily available, inexpensive, and more versatile for manual inter-
pretations.   The methods developed and analyzed include stereo modeling,
snow enhancement, stereo reversal, seasonal combinations, and diazo
color composites.   The use of the term "stereo" in this report is as
it applies to a three-dimensional visual model created by the super-
position of adjacent LANDSAT frames using a stereoscope.   The term
"stereo" will not necessarily apply to stereoscopic paralax in the
same sense as conventional air photos.

E.5.1. Methods.

Standard products. Among the LANDSAT products readily available from the EROS data center, the 9" by 9" black and white transparencies are the most useful. In comparison with prints at the same scale, transparencies inherently provide better resolution and yield more information. Transparencies can be used with variable intensity light sources and as a source for diazo color composites. Prints are useful as a base for the transfer of information and for public displays.

Although individual black and white transparencies yield a fair amount of geomorphic information, the best method by far is stereo pairing of adjacent images. This is standard technique for geologists and geomorphologists with air photos, but is even more important with satellite imagery where tonal changes at a scale of 1:1,000,000 are necessary but often not sufficient for delineation of features. The 33% overlap at this latitude provides 60% of the planning unit with good stereo coverage (portions to the east in the Rio Grande and Carson National Forests are not covered).

In addition to this "good" stereo, a slight stereo view is available for the entire area because of the normal drift in LANDSAT I. During 1973, the satellite drifted slightly off course so that the September 20 and 21, 1973 (1424-17132 and 1425-17190) images are offset about 10% to the west when compared with earlier images from LANDSAT I and all images from LANDSAT II. When the shifted September image is combined with a "normal" image of the same scene, the 10% offset produces slight yet highly useful stereo coverage for the planning unit. This was utilized for geomorphic mapping in the regions beyond the usual stereo coverage.

Standard black and white LANDSAT transparencies were evaluated in a stereo mode. The best overall images for the Southern San Juan Mountains were 1424-17132 and 1425-17190 of September 20 and 21, 1973. Band 5 is optimum for geomorphic mapping of these fall images where vegetation tonal contrasts are greatest. Unfortunately, Band 5 of 1424-17132 is not available due to damage of the original data tapes. LANDSAT frame 2222-17020 of September 1, 1975, provided a suitable substitute, although clouds covered 10-15% of the planning unit.

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Stereo viewing of 1425-17190 Band 5 with 1424-17132 Band 7 was also used.

Light snow cover may enhance subtle differences in topographic expressions. During the first phase of the project, the best LANDSAT images for this purpose were 1190-17145 and 1191-17204 of January 29 and 30, 1973. That late in the season, however, snow cover is no longer uniform due to redistribution of snow by wind. Fortunately, the fall of 1975 provided optimum conditions for several cloud-free, early winter images (2259-17073, October 8, 1975; 2276-17013, October 25, 1975; 2294-17012, November 12, 1975). The light, uniform snow falls during October and November were followed by warm, sunny days. This allowed differential melting of south and west facing slopes while north and east facing slopes remained snow covered. The sharp contrast between these slope aspects, further enhanced preferentially by the low sun angle, enable delineation of subtle geomorphic features not visible on other LANDSAT images. Stereo-pairing of adjacent early winter images (in particular, 2259-17073 and 2276-17013) aided identification of topographic features such as landslides and drainage patterns. Band 7 of these snow-covered frames provided the sharpest image.

With the above mentioned images, several other combinations were useful for discerning geomorphic features. Combining a September image with an early winter image in stereo also enhanced the terrain, even to a somewhat greater extent than images of the same season. Reversing the stereo by reversing the position of the images under the stereoscope enhances bottomland features. In normal stereo viewing, the eye is automatically drawn to features of positive relief. Ridges are seen in more detail than negative relief features such as valleys and bottomland features. Stereo reversal brings these negative relief features into positive relief where the eye perceives more detail. Several alluvial fans not recognized with normal stereo were mapped with stereo reversal.

Diazo color composites. Because the human eye can distinguish 350,000 continuous color variations as opposed to only 200 shades of gray, a color display of LANDSAT data is optimum for manual interpretation (Warrington and Ryerson, 1974). Only two standard color composites

are produced by the National Air Photo Library whereas other band color combinations may better enhance particular feature of interest. Diazo color composites provide an easy and inexpensive means to manipulate other composite combinations. Three colors (usually the additive primaries red/blue/green, or the subtractive primaries cyan/magenta/yellow) are used with three of the four LANDSAT bands (usually Bands 4, 5, and 7). When both positive and negative transparencies are combined, 48 different three band/three color combinations are possible.

The main advantage of the diazo process is the cost. Ready made color composite transparencies from NASA cost $12 each. For each color composite not already on file, an additional $50 is assessed. A set of the 18 diazo color separates needed to make all 48 color composites costs about $5.50. Materials used in experimentation to determine the correct exposures cost $10 for each frame. Even with the additional cost of the original positive and negative transparencies, diazos are less expensive and far more flexible for different interpretation needs than the standard composites.

The main disadvantage of diazo color composites is that some resolution is lost. The separate bands are difficult to register with one another. The layering effect when viewed with magnification confuses the interpretations to some degree. Because diazos are another step beyond the original data, some information and resolution is lost in the translation. A stereo model using adjacent diazo composites is possible; however, when magnified greater than 3X, resolution is poor due to the layering effect and registration difficulties. However, the cost and flexibility of diazos far outweigh the slight loss of resolution.

The diazo process involves film coated with a compound sensitive to ultraviolet light. The emulsion side of a LANDSAT transparency is placed on the emulsion side of the diazo film and is exposed to an ultra- violet light source. The film is then "developed" with ammonia vapor. For this effort, a model 101 Diazo Printer and a model 202 Developer from the Arkwright-Interlaken, Inc. were utilized, courtesy of the U.S. Geological Survey, Air Photo Division, Denver Federal Center.

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Cyan, magenta and yellow diazo transparencie. were created for both positive and negative transparencies of Bands 4,5, and 7 from LANDSAT images 1425-17190, September 21, 1973, and 2222-17020, September 1, 1975. Exposure times vary depending on the relative density of the LANDSAT frames of interest, and thus, a small amount of experimentation is necessary (Table E.5). In general, cyan diazos will require about a half minute longer exposure than yellow diazos, and exposures for magenta diazos will be nearly twice that of yellow. For the mountainous, well vegetated southern San Juan Mountains, "light" images such as positive Band 7 and negative Bands 4 and 5 require exposure times between one and five minutes. Because diazo film cannot be overdeveloped, prolonged exposure to ammonia vapor will not turn the image uniformly dark. Thus, development time was no problem.

The 48 possible composite combinations were evaluated and treated in terms of utility for landform mapping (Table E.6). The most useful composites are those with good color contrast as well as sufficient color variation. It should be noted that these evaluations pertain only to composite combinations of one frame, 2222-17020. Other frames in other seasons or in other areas will have different optimum combinations. Also, only composites of three colors and bands were evaluated, and only for application to the geomorphic studies indicated above. Many of the two-band or color combinations may be of use for different studies. More colors may be added to the master set to give almost unlimited combinations.

From the systematic evaluation of the 48 diazo combinations, the following observations were made:

1) Combinations with negative band 7 were universally poor. Diffraction of the ultraviolet light during the long exposure time required produced a fuzzy image of very poor resolution. Thus, 24 combinations are effectively eliminated.

2) The best combinations involve a positive band 7 with a positive band 4 (or 5) and a negative band 5 (or 4). When bands 4 and 5 are both positive or negative, less color variation is evident.

3) The interchanging of bands 4 and 5 gave similar images with no new information content. For example, positive band 4 in yellow,

TABLE E.5.

EXPOSURE TIMES FOR DIAZO COLOR COMPOSITES
(for Arkwright-Interlaken Model 101 Printer).

Color	LANDSAT Frame	Band	Positive Exposure (Minutes)	Negative Exposure (Minutes)
Yellow	1425-17190	4	7½	1
	"	5	7	1
	"	7	3	6
	2222-17020	4	6½	2
	"	5	6	1½
	"	7	1½	12
Cyan	1425-17190	4	7½	2
	"	5	7	1½
	"	7	3	6
	2222-17020	4	7½	2
	"	5	7	1½
	"	7	2½	10½
Magenta	1425-17190	4	12	1
	"	5	12	3/4
	"	7	5½	6
	2222-17020	4	11	22
	"	5	10½	1½
	"	7	3	24

TABLE E.6.

DIAZO COLOR COMPOSITE COMBINATIONS

Best Color Contrast and Color Variation	Good Contrast But Less Color Variation	Poor Resolution

P4Y + P5M + P7C
  (P4M + P5Y + P7C)
	N4Y + N5M + P7C
	  (N4M + N5Y + P7C)
		P4Y + P5M + N7C
		    (P4M + P5Y + N7C)

P4Y + N5M + P7C
  (N4M + P5Y + P7C)
	P4Y + P5C + P7M
	  (P4C + P5Y + P7M)
		P4Y + N5M + N7C
		    (N4M + P5Y + N7C)

N4Y + P5M + P7C
  (P4M + N5Y + P7C)
	N4Y + N5C + P7M
	  (N4C + N5Y + P7M)
		N4Y + P5M+ N7C
		    (P4M + N5Y + N7C)

P4Y + N5C + P7M
  (N4C + P5Y +P7M)
	P4M + P5C + P7Y
	  (P4C + P5M+ P7Y)
		N4Y + N5M + N7C
		    (N4M + N5Y + N7C)

N4Y + P5C + P7M
  (P4C + N5Y + P7M)
	P4M + N5C + P7Y
	  (N4C + P5M +P7Y)
		P4Y + P5C + N7M
		    (P4C + P5Y + N7M)

	N4M + P5C + P7Y
	  (P4C + N5M + P7Y)
		P4Y + N5C + N7M
		    (N4C + P5Y + N7M)

	N4M + N5C + P7Y
	  (N4C + N5M + P7Y)
		N4Y + P5C + N7M
		    (P4C + N5Y + N7M)

	P4M + P5C + N7Y
	  (P4C + P5M + N7Y)
		N4Y + N5C + N7M
		    (N4C + N5Y + N7M)

	N4M + N5C + N7Y
	  (N4C + N5M +N7Y)
		P4M + N5C + N7Y
		    (N4C + P5M + N7Y)

		N4M + P5C + N7Y (P4C + N5M + N7Y)

KEY
P = positive
N = negative
Y = yellow
M = magenta
C = Cyan
4 = Band 4
5 = Band 5
7 = Band 7
(   ) similar composite

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negative band 5 in magenta, and positive band 7 in cyan is essentially the same as positive band 5 in yellow,. negative band 4 in magenta, and positive band 7 in cyan. The 24 combinations which are similar to the other 24 are shown in parentheses in Table E.6.

4) With the colors assigned to bands 4, 5, and 7 remaining the same, interchanging the signs of bands 4 and 5 produced complimentary composites. For example, a composite with positive band 4 in yellow, negative band 5 in magenta, and positive band 7 in cyan is complimented by the composite with negative band 4 in yellow, positive band 5 in magenta, and positive band 7 in cyan. Features emphasized in one composite will not be emphasized as much in the complimentary composite. Following this evaluation of the composite combinations, only the 10 best were further evaluated as tools for geomorphic mapping.

Using the techniques previously outlined, drainage patterns, landslides, bottomland features and glacial deposits were mapped and compared to previous mapping efforts of the U.S. Geological Survey and others. Each map reflects the cumulative results from all methods.

E.6. Geomorphic Features Mapped.

E.6.1. Drainage Pattern. Drainages were mapped primarily using band 7 stereo pairs of the early winter images (2259-17073 and 2276-17013). Because the snow cover was somewhat less extensive on October 8, 1973 (2259-17073), the terrain was also enhanced by the "seasonal" contrast. Where snow was somewhat heavier on the high uplands near the Continental Divide, and where snow was absent in the lower elevations, September stereo pairs were used (1425-17190 band 5 with 2222-17020 band 5, or 1425-17190 band 5 with 1424-17132 band 7). Beyond the point of good stereo coverage, 10% stereo and seasonal enhancement using LANDSAT images 1424-17132 band 7 and 2276-17013 band 7 filled the gap. Drainages seen on the LANDSAT stereo pairs were mapped onto a 1:250,000 base using the zoom transfer scope.

The drainage pattern map as derived from LANDSAT (Figure E.2) is considerably more detailed than that derived from the Durango 2° base map (Figure E.3). A finer drainage density and many more lakes were recognized from LANDSAT. This is potentially beneficial to the U.S.

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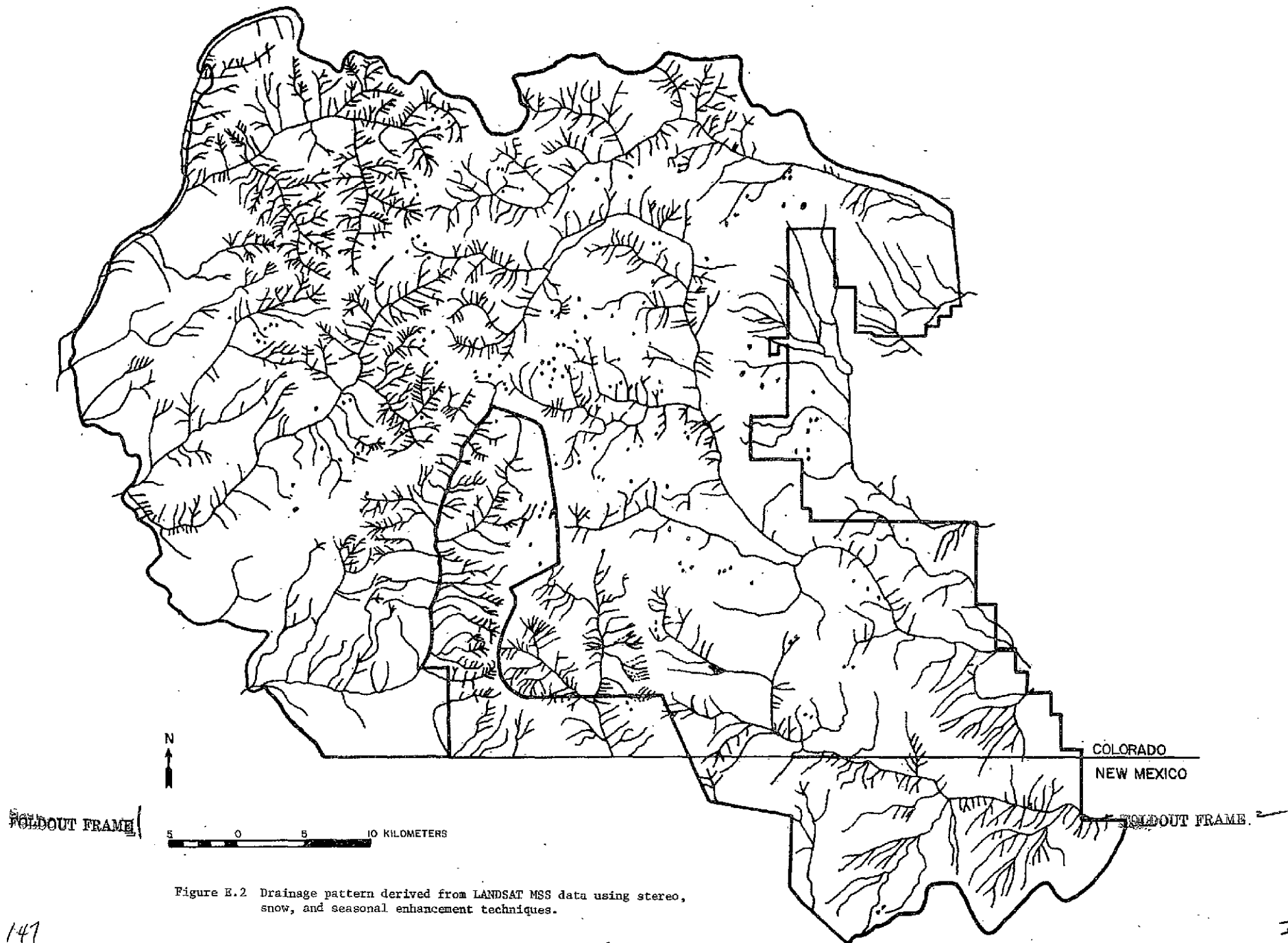
Figure E.2 Drainage pattern derived from LANDSAT MSS data using stereo,
snow, and seasonal enhancement techniques.

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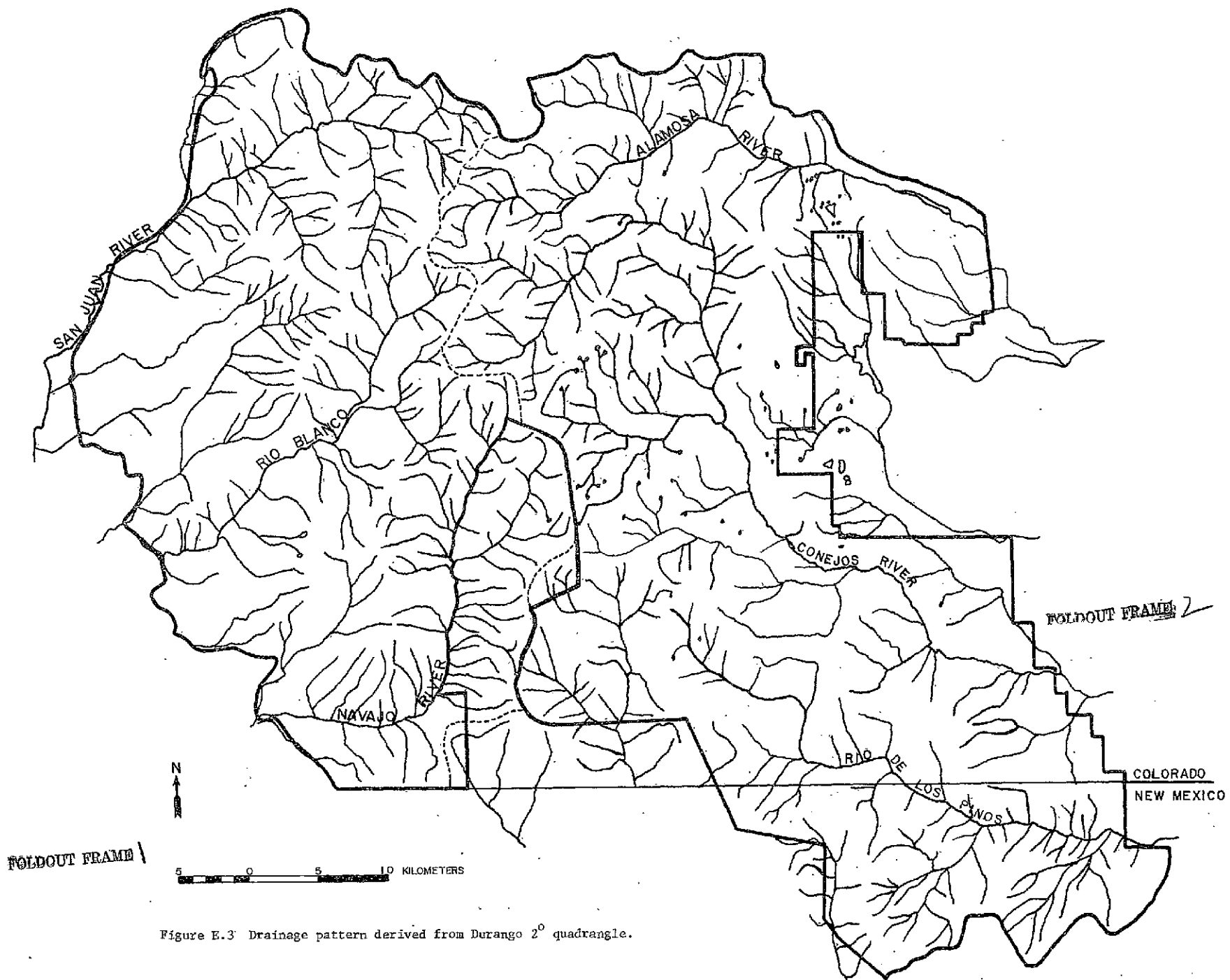
Figure E.3 Drainage pattern derived from Durango 2° quadrangle.

Forest Service for mapping the aquatic units (Table E.7) which comprise the Ecological Water Units along with landtype associations. Meandering streams, such as the Alamosa, Conejos, Navajo and San Juan Rivers, can be discerned from LANDSAT. The different degrees of dissection of mountain streams are also apparent as are large and small lakes.

Drainage patterns are also useful in interpreting the underlying geology. According to H.J. Way (1973, p.5), "Drainage is studied according to its pattern type and its texture or density. It is probably the most important single identifier of landforms. Drainage pattern analysis can give a great deal of information concerning the parent rock and soil materials, since these influence the amount of runoff and how the water runs off or drains from a landform surface." Detailed analysis of changes in drainage patterns may provide an alternative basis for U.S. Forest Service land systems mapping. . This would involve approaching the Land Systems Inventory using a different description base to define landforms.

Drainage texture reflects bedrock resistance and permeability; coarse for resistant, permeable rock types such as granite; fine for impervious bedrock such as shale; and medium for everything in between. The six basic drainage patterns (Table E.8) reflect major lithologic and structural controls while the modifications of these basic patterns (Table E.9) reflect more specific controls. Generally, drainage pattern analyses are carried out at a scale of 1:24,000 or larger. Therefore, the major drainage patterns apparent on LANDSAT may not mean exactly the same things as patterns at the larger scale. However, the general implications will be the same. Dendritic patterns imply homogeneity of rock type, but the degree of homogeneity will depend on the scale. The coarser drainage textures on LANDSAT reflect more resistant, permeable bedrock, yet the truly fine-textured drainage of shale cannot be resolved at the scale of LANDSAT. Thus the shales cropping out on the western edge of the planning unit show a medium to coarse texture over most of the area.

.The drainage patterns derived from LANDSAT were analyzed on the basis of pattern changes and known bedrock geology. One of the major pattern changes occurs at the Continental Divide where the western

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Table E.7. Aquatic Units.

Unit	Description
Meandering Streams	A stream that winds laterally downstream flowing through flat alluvial valleys. The water flow is usually perennial.
Dissected Mountain Stream	Small mountain streams flowing through steep sided valleys. The water flow is usually perennial.
Poorly Defined Grassed Drainages	Drainages with shallow, bare or grassy channels usually flowing through gently rolling terrain. The water flow is usually intermittent.
Small, Moderately Dissected Drainages	Drainages with numerous channels flowing through gently to moderately steep terrain. The water flow is usually intermittent.
Undefined Drainages	Drainages where the water flows over the land and rocks rather than in defined channels. The water flow is usually intermittent.
Poorly Defined Rock Drainages	Rocky, precipitous channels draining steep sided canyons. The water flow is usually intermittent.
Weakly Dissected Mountain Streams	Streams usually with well defined channels and rubble bottomed, flowing over benched terrain. The water flow is usually perennial.
Semi-Drainage Lakes	Small, shallow, pond-like lakes lacking perennial water flowing in surface inlets and outlets. These lakes usually support rooted and aquatic vegetation.
Drainage Lakes and Reservoirs	Lakes and reservoirs of varying size with definite water flowing inlets and outlets, insignificant changes in surface elevation. These usually lack rooted aquatic vegetation, except near their edge.

Table E.8. Basic Drainage Patterns and Geologic Implications
(after Parvis, 1950; Way, 1973).

Dendritic   Trellis   Radial   Parallel   Annular   Rectangular
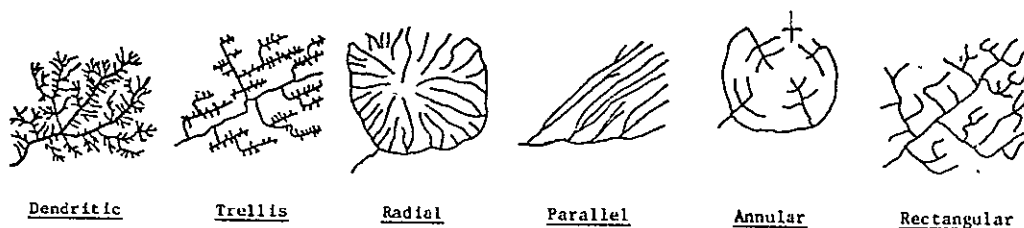
Dendrite: tree-like branching system in which tributaries join main-
               stream at acute angles; indicates homogeneous, uniform
               soil and rock materials; typical of soft sedimentary rocks,
               volcanic tuff, thick glacial till.

Trellis: modified dendritic forms with parallel tributaries and
               short parallel gullies occurring at right angles; indi-
               cates bedrock structure such as tiltled, interbedded
               sedimentary rocks in which the main parallel channels
               follow the strike of the beds.

Radial: circular network of almost parallel channels flowing
               away from a central high point with major stream incur-
               vilinear alignment at base; indicates volcanoes, isolated
               hills, domelike landforms.

Parallel: parallel streams; indicate homogeneous, gentle, uniformly
               sloping surface; main streams if non-parallel may indicate
               fault; typical of large basalt flows.

Annular: ring-like tributaries flow into radial streams; bedrock
               joints, fractures, control tributaries; typical of granite
               on sedimentary domes.

Rectangular: tributaries join mainstream at right angles; indicates
               control of bedrock jointing, foliations or fracturing.

Table E.9. Modified Drainage Patterns and Geologic Implications
(after Parvis, 1950; Way, 1973).

| Pinnate | Subparallel | Subdendritic | Angulate | Deranged | Barbed |
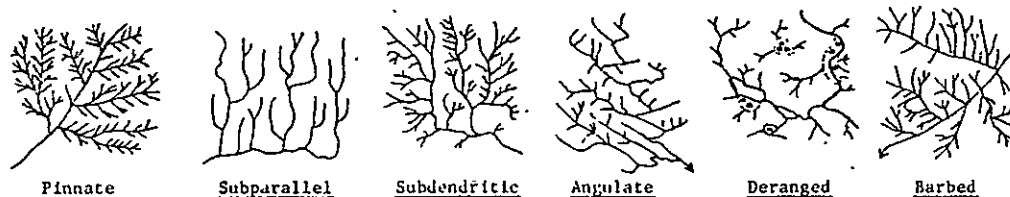
Pinnate: modified dendritic pattern with feather-like branching
                pattern in which tributaries join mainstreams at acute
                angles; indicates high silt content.

Subparallel: modified parallel pattern but lacks regularity; indi-
                cates uniform slope.

Subdendritic: modified dendritic pattern with minor slope control of
                second and third order streams; indicates streams flowing
                from non-resistant material area through another of
                slight structural control.

Angulate: modification of rectangular or trellis pattern with
                junction angles other than right angles; indicates
                system of faults, fractures or joints.

Deranged: non-integrated drainage of relatively young landforms
                with flat or undulating surface and high water table;
                typical of moraines, flood plains, landslides.

Barbed: spurred pattern; modification of other drainage patterns
                when tectonic disturbance or stream capture reverses
                direction of mainstream.

portion of the planning unit shows finer textured pinnate and dendritic drainage and the eastern portion reveals much coarser dendritic, annular and radial patterns. The climate on either side of the Divide varies as does the bedrock geology. Volcaniclastics dominate on the west while the more resistant lava flows originating from volcanic centers dominates on the east. On the western flanks of the mountains, the contact between Mesozoic sandstones and shales and Tertiary volcanics occurs at the abrupt change in drainage pattern from coarse dendritic to finer dendritic and pinnate drainages. Other such patterns are indicated on Figure E.4.

E.6.2. Landslides.

Landslides and related mass movements are a common phenomena in the southern San Juan Mountains (Figure E.5). They occur any place where there is a slope but tend to be concentrated along key geologic discontinuities or within certain formations. The Mancos and Lewis shales are the main culprits along the western flank of the mountains. Small slides have occurred where sandstone beds overlie these shales, but the numerous large landslides occur where these shales underlie the thick formations of volcanic breccias (Atwood and Mather, 1932; Larsen and Cross, 1956). In the eastern portion of the planning unit, landslides are generally smaller and somewhat less common than in the western portion of the planning unit. Here landslides commonly occur within the Treasure Mountain tuff. The alternating resistances of individual ash-flow units react in the same manner as alternating beds of shale and sandstone with failure occuring in the weaker units. Other tuff formations within the planning unit are associated with slides for the same reason. These formations are especially vulnerable to mass movements because of the oversteepening of valley walls by glacial ice.

Typical landslide features which can be identified with remote sensing techniques include a prominent scarp, hummocky topography, deranged drainage, undrained depressions, and disrupted topographic and vegetation patterns. The presence of two or more of these features is often, though not necessarily, sufficient to identify a landslide mass. All of the above features can be detected with stereo viewing of LANDSAT

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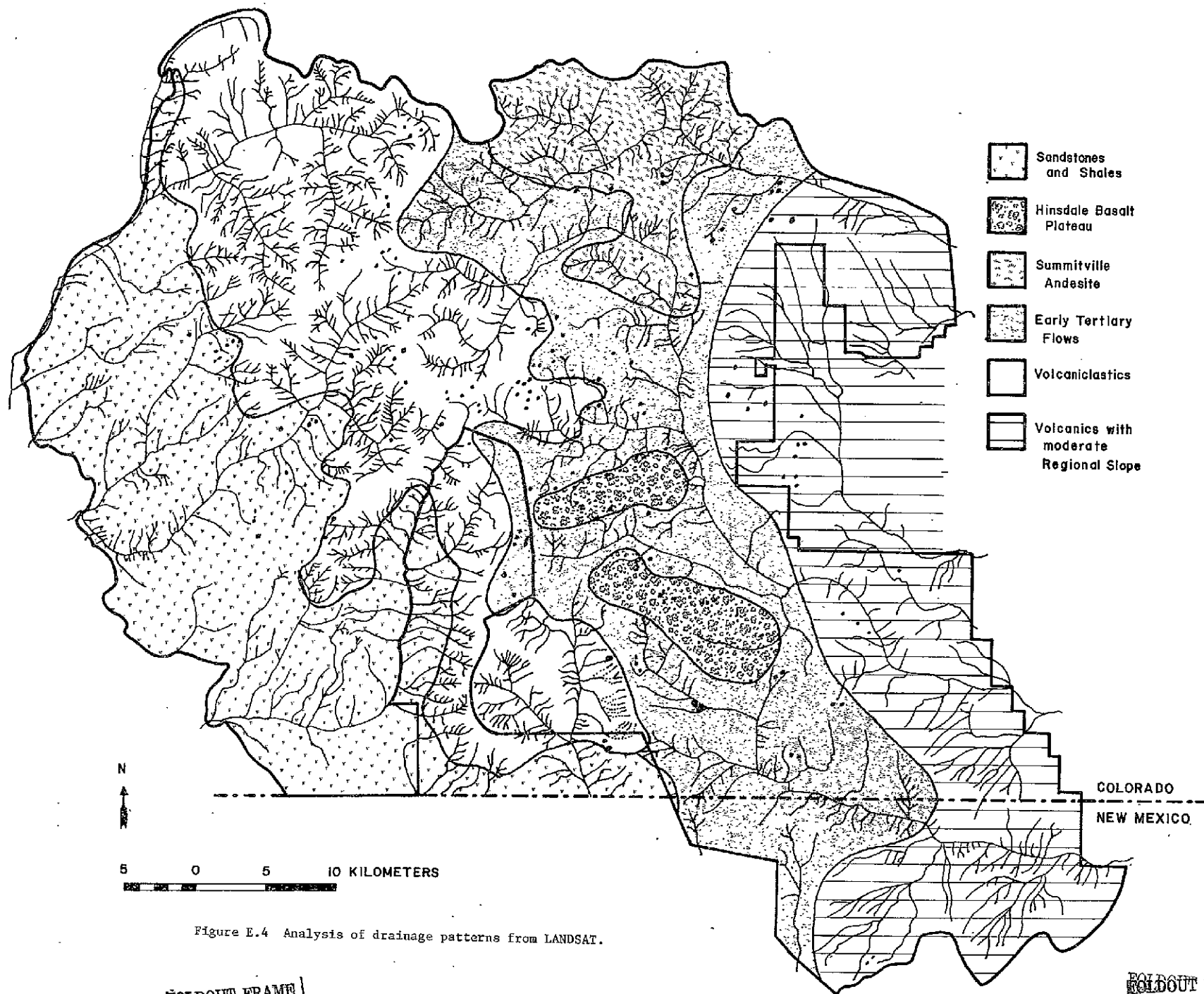
Figure E.4 Analysis of drainage patterns from LANDSAT.

Legend:

- Sandstones and Shales
- Hinsdale Basalt Plateau
- Summitville Andesite
- Early Tertiary Flows
- Volcaniclastics
- Volcanics with moderate Regional Slope

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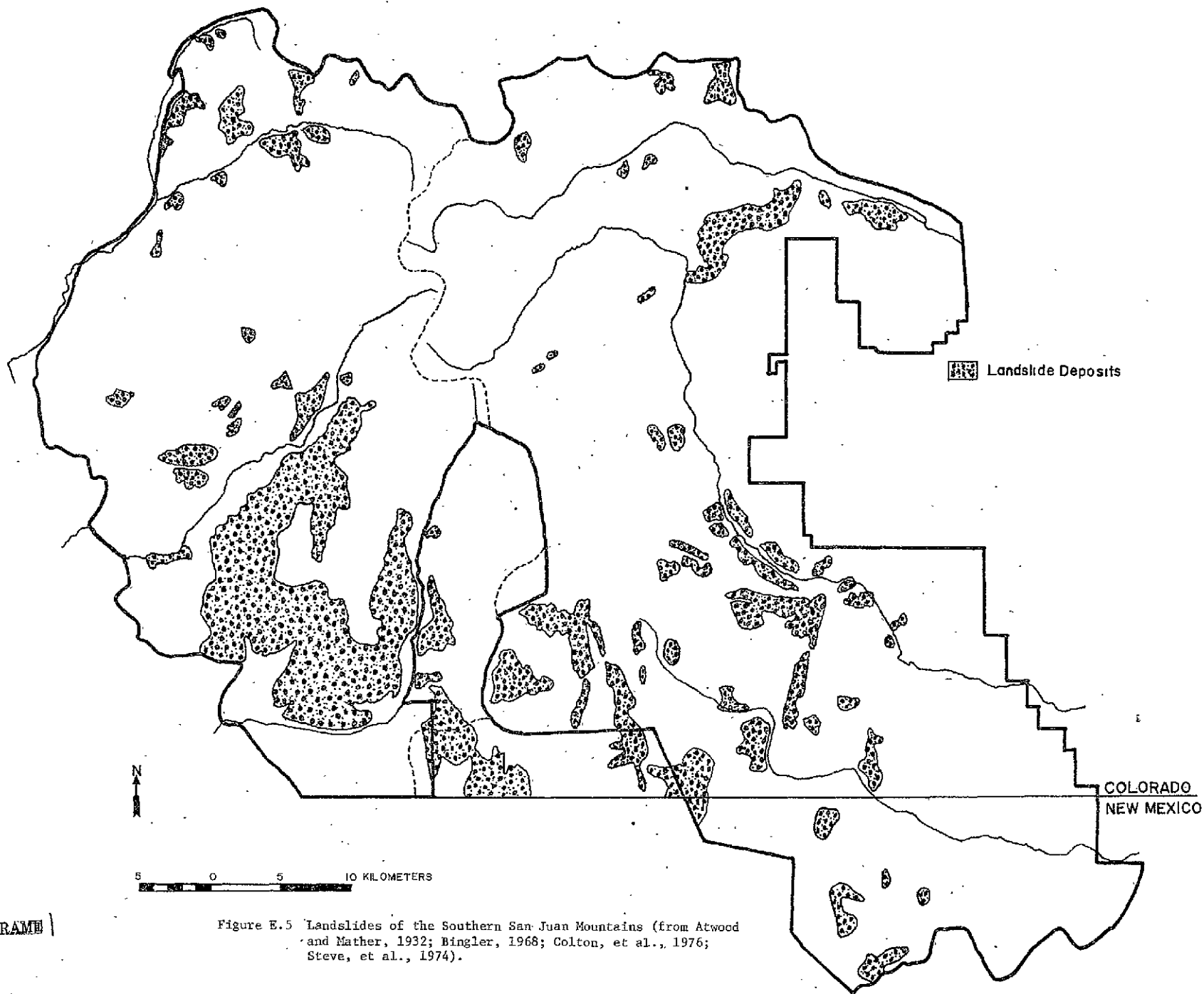
Figure E.5 Landslides of the Southern San Juan Mountains (from Atwood
and Mather, 1932; Bingler, 1968; Colton, et al., 1976;
Steve, et al., 1974).

imagery, although scarps are visible only on relatively recent, large landslides (such as the East Fork landslide). Unc⁻ained depressions, when present and larger than about 25 hectares, are easily detected on September Band 7 images. The hummocky topography itself cannot be consistently recognized, for the scale of "hummocks" in a landslide is often smaller than the stereo resolution of the LANDSAT images. However, this hummocky topography is often enhanced by snow cover or vegetation. The result on LANDSAT imagery (1425-17190 and 2222-17020 Band 5 for vegetation, and 2259-17073 and 2276-17013 Band 7 for snow enhancement) is a mottled appearance from tonal differences. On diazo color composites this mottling is even more distinctive because of the strong color contrasts (in particular Pos.4Y + Neg .5M + Pos.7C and Pos.4Y + Neg5C + Pos.7M of Table E.6).

Perhaps the most diagnostic feature for landslide recognition on LANDSAT is the disruption of drainage, topography and vegetation patterns (Figure E.6). The characteristic mottled appearance is one pattern change which may contrast sharply with adjacent undisturbed terrain. The deranged drainage within a slide is often difficult to detect in itself, yet the change in drainage pattern above and below a slide can be quite distinct. For example, the large landslide mass on the east side of the Rio Chama is recognized by the mottled appearance, undrained depressions, lack of defined drainage within the slide, and abrupt changes in drainage patterns adjacent to it. The steep terrain of volcanic breccia above the slide is cut by numerous parallel drainages which on LANDSAT images appear to end abruptly at the slide mass (Figure E.2). The subparallel drainage of the sandstones and shales below this area start just as abruptly.

Other pattern elements may be disrupted by landslides. Any moderate valley slope tends to develop patterns that roughly parallel the slope. Landslides generally create patterns which crosscut the slope (scarps, flow ridges, slumpblocks, etc.). Thus, a change from downslope patterns to crosscutting patterns may indicate landsliding as exemplified by the small slides on the east side of the Navajo River and the south side of Elk Creek.

The cumulative effect of these features when viewed on a LANDSAT

Figure E.6.   East Fork landslide on the East Fork of the San Juan River.
This landslide shows many of the diagnostic features such
as a prominent scarp, undrained depressions, hummocky topo-
graphy, deranged drainage, and disrupted topographic and
vegetation patterns. The mottled appearance of the vegeta-
tion reflects the hummocky topography and unstable nature
of the land mass. The diagnostic features are more easily
detected when viewed in stereo. (LANDSAT scene 2222-17020,
October 25, 1975)

image suggests to the interpreter that something is different or "abnormal" about the slope development of that area. In this study, only the slides along the Navajo River were known prior to beginning the interpretation. Other suspected landslide areas in the near vicinity were mapped by the presence of features similar to those known areas. These were then checked against geologic base data (Fig. E.5) before continuing with the interpretation. The interpreter thus developed a trained eye for recognizing landslide areas throughout the planning unit.

All methods previously discussed were utilized for mapping landslide areas (Fig. E.7). Each technique alone was sufficient to map most of the landslides but the combination of several increased the reliability. In comparing this map to that of known landslide areas (Fig. E.5), most large landslides and moderate-sized slides in steep terrain could be detected with LANDSAT. Only the very small or subdued slides could not be recognized.

E.6.3. Alluvium and glacial deposits.

Floodplains, terraces, and alluvial fans are found along most major drainages in the southern San Juan Mountains. Glacial deposits from the Cerro, Durango, and late Wisconsin glaciations (Table E.2) can be found high on upland surfaces, along valley walls, and along the floors of major valleys (Fig.E.8).

Using LANDSAT images in a stereo mode with snow enhancement, seasonal enhancement, and stereo reversal, most alluvial deposits and several glacial deposits were mapped (Fig. E.9). For bottomland features, stereo reversal of LANDSAT images provided the most information. However, the resolution even in this reversed stereo mode was not sufficient to separate individual alluvial terraces, floodplains, alluvial fans, glacial outwash terraces, and glacial moraines. This provided instead the capability for more accurate delineation of bottomlands in general and the recognition of a few specific alluvial fans along the Navajo and San Juan Rivers.

In general, LANDSAT MSS data has insufficient resolution for mapping glacial deposits in valley positions. Alluvium and glacial deposits were indistinguishable and were thus mapped as alluvium (Fig. E.9). Only the large accumulations of glacial till on the uplands above the Conejos River were recognized by their blocky morainal form.

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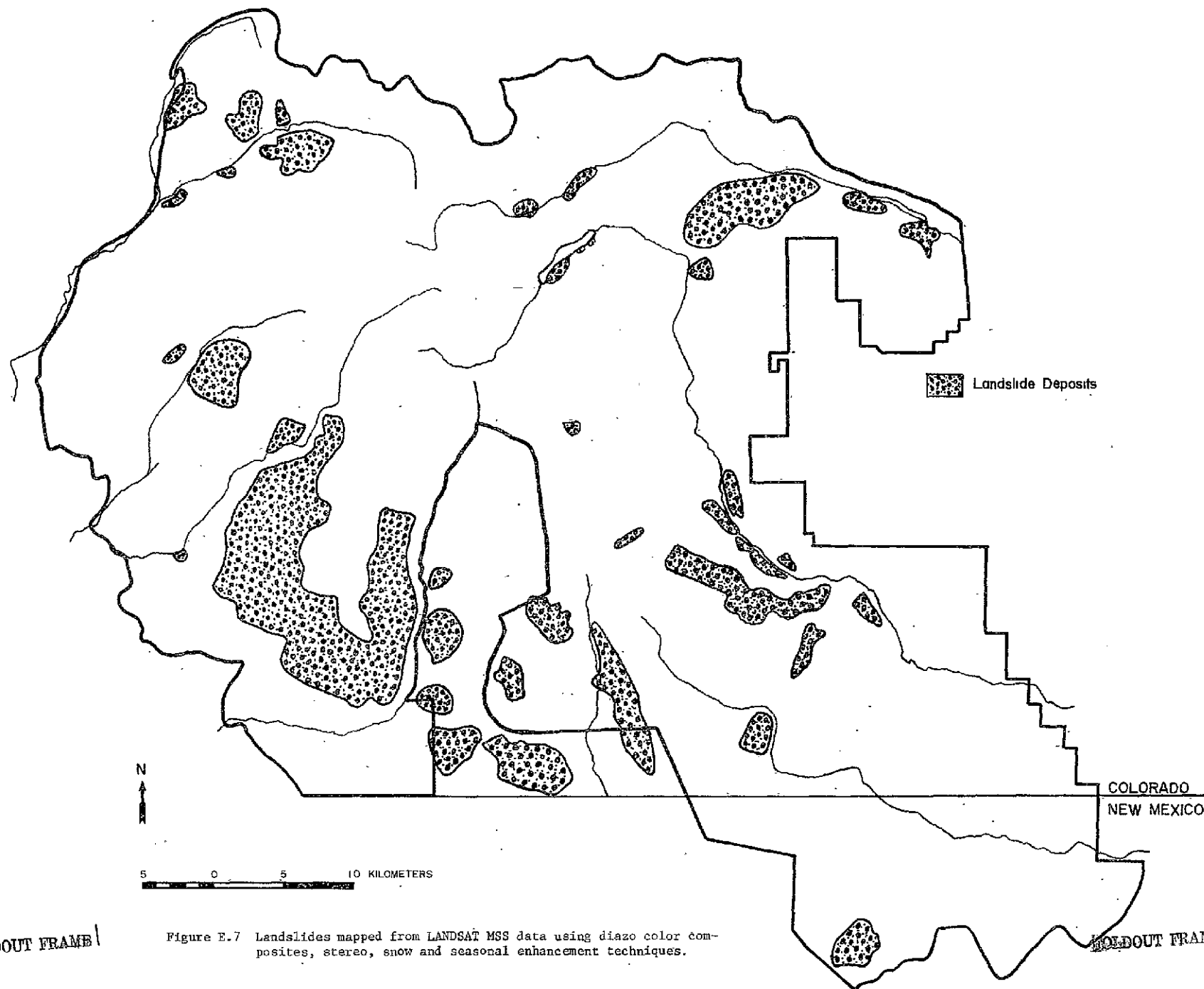
Figure E.7   Landslides mapped from LANDSAT MSS data using diazo color com-
posites, stereo, snow and seasonal enhancement techniques.

Legend:

Alluvium (*includes terrace, floodplain, alluvial fan, and glacial outwash deposits.*)

Glacial Till (*of Cerro, Durango, and Wisconsin glaciations.*)

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Figure E.8   Alluvium and Glacial deposits of the Southern San Juan Mountains (after Atwood and Mather, 1932; Bingler, 1968; Steven et al., 1974).
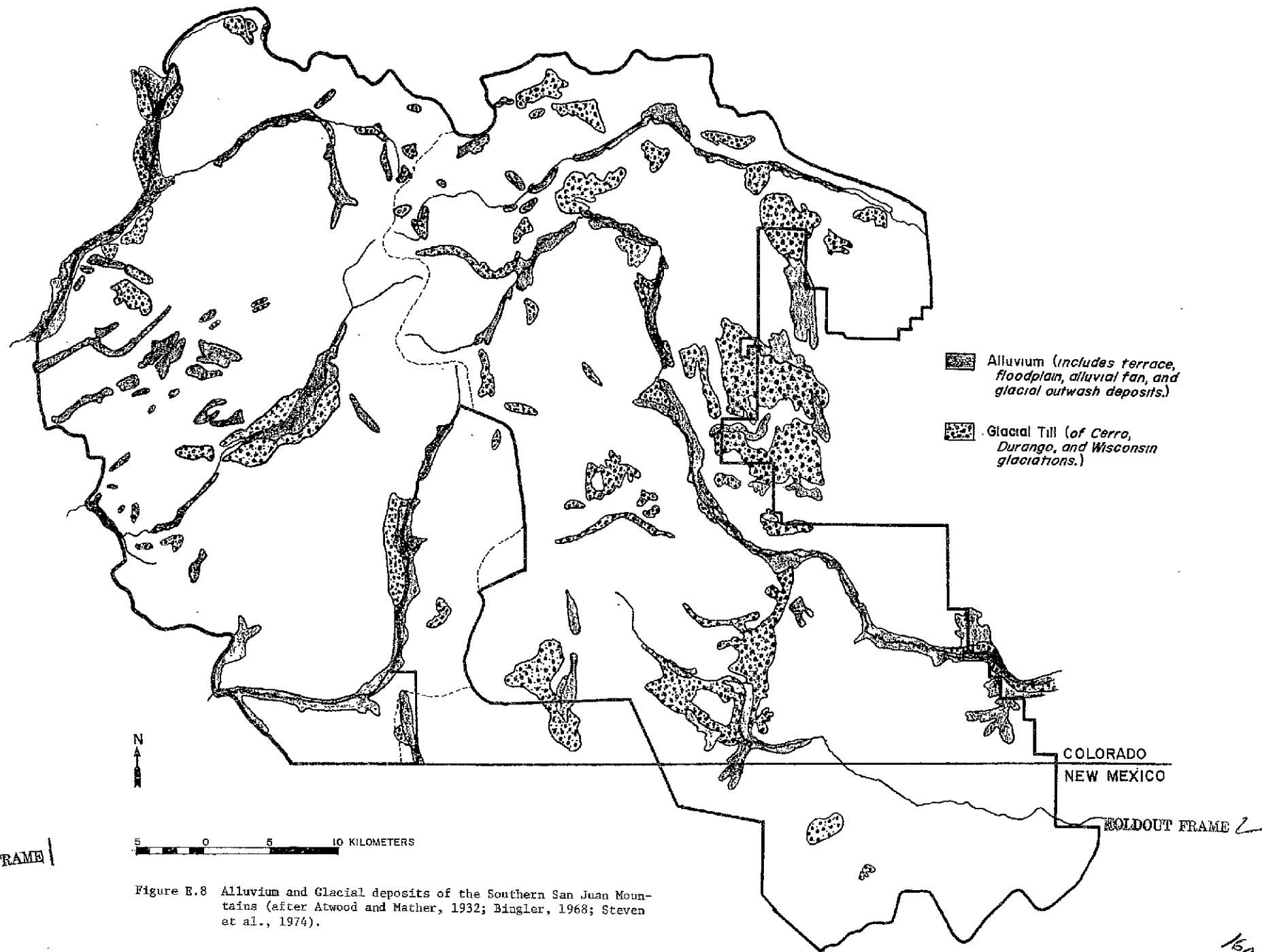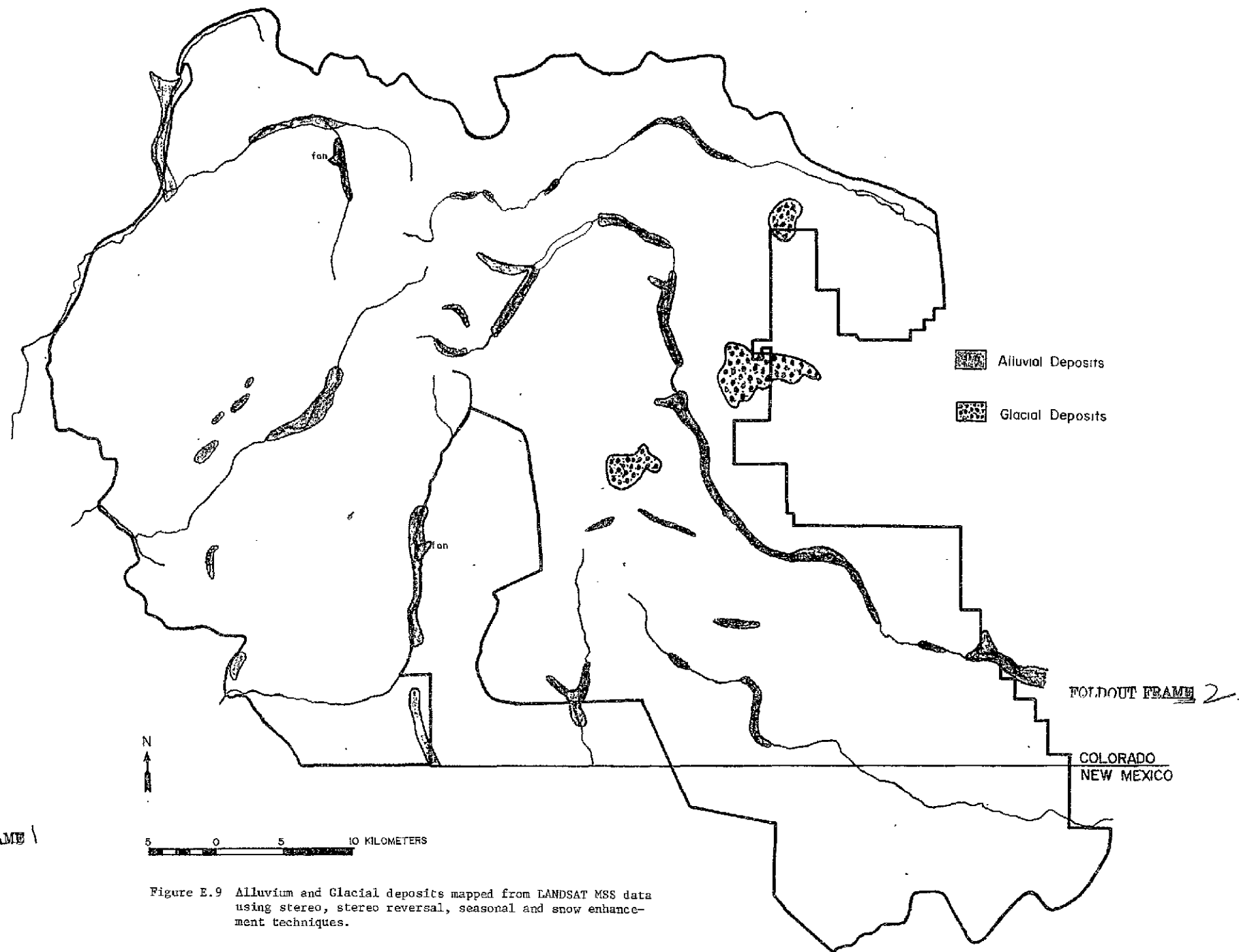
Figure E.9 Alluvium and Glacial deposits mapped from LANDSAT MSS data using stereo, stereo reversal, seasonal and snow enhancement techniques.

E.7. Conclusions.

LANDSAT MSS imagery provides an excellent overview which can put any geomorphic study, regardless of scale, into a regional perspective.

LANDSAT is an excellent tool for regional geomorphic studies at a scale of 1:250,000 or smaller.

It is useful for deriving base data for land use planning at the scale needed for the Southern San Juan Mountains Planning Unit. Although the system used by the Forest Service may give problems to interpreters outside the Forest Service, LANDSAT is potentially valuable in-house evaluation of landtypes and landtype associations.

Stereo pairing of adjacent images is the best method for all geomorphic mapping. Combining this with snow enhancement, seasonal enhancement and reversal further enhances specific geomorphic features.

Diazo color composites are inexpensive, easily obtained and versatile for geomorphic mapping, and landslide recognition in particular.

Drainage patterns may be mapped in much greater detail from LANDSAT than from a 2° quadrangle base.

Bottomlands are easily mapped but individual features cannot be distinguished. Only large accumulations of glacial till can be recognized on LANDSAT.

Landslides can be accurately mapped at the scale of 1:250,000 using diazo color composites, and stereo models of snow and seasonal enhancements.

The usefulness of LANDSAT as a tool in geomorphic mapping is increased when the areas of interest can be viewed in stereo mode. A recommendation is that the orbit track of future LANDSAT-type systems be shifted to midway between those of LANDSAT -1 and -2. This would allow stereo viewing of all earth surface areas by combining frames of LANDSAT-C with LANDSAT-1 or LANDSAT-2, and with adjacent LANDSAT-C frames.

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COST EFFECTIVE ANALYSIS

P.V. Krebs, INSTAAR   J.P. Spencer, INSTAAR

A cost effective evaluation was made for the final products resulting from this study. These figures are based on several assumptions: 1) the user group has expressed definite needs which can be met by analysis of LANDSAT MSS data, 2) experienced and knowledgable ecologists who are familiar with the study area are working in close conjunction with experienced computer analysts who are familiar with the programs available, and 3) everything goes right the first time, (i.e., "Murphy's Law" is not applicable). An honest evaluation of the personnel time involvements has been made for each phase of the project. The final figures reflect a full season of field work, support data interpretation, LANDSAT MSS data pre-processing, and derivation of training statistics, as well as the actual classification, data manipulation processes, and mapping.

The cost analysis is based on three distinct types of expenditures: personnel time, computer time, and materials. The expenditures for each aspect of the study may be tabulated and then summarized in an overall cost per unit area. The following tables list the data for time involvement, computer costs, and materials cost for the vegetation classification, topographic data overlay, and geomorphic mapping.

A necessary consideration in a cost/effective analysis is the personnel time involved in carrying the study to completion (Table F.1). The various phases of the study span a certain time interval out of which a specific amount of personnel time was expended. This includes orientation sessions with the U.S. Forest Service, field work, data preparation for vegetation classification and evaluation, and other activities directly related to technology transfer and product applications.

The personnel time necessary for all phases of the computer-aided analysis of LANDSAT MSS data is summarized in Table F.2. Included here is the time required in field work, development of training statistics, and evaluation calculations. The personnel time

involved in the geomorphic mapping is summarized in Table F.3. Preparation of interpretation materials and the actual time required for mapping are tabulated separately.

The cost of necessary materials for the vegetation analysis, topographic data overlay, and geomorphic mapping is listed in Table F.4. Computer costs (Table F.5) apply to the vegetation analysis and topographic data overlay. Each major step of the analyses procedures is listed separately. The unit cost for computer time for the combined vegetation classification and topographic data overlay is $0.012/hectare ($0.0049/acre), or $182.26 for one 7 1/2' U.S.G.S. quadrangle. The computer time includes pre-processing and geometric correction, development of training statistics, classification, evaluation, topographic data registration to the LANDSAT MSS data, slope and aspect calculations, and merge run plus ten combinations.

The overall cost analysis (Table F.6) for the final products derived for the Southern San Juan Mountains Planning Unit was $17,907.00 (463,885 hectares or 1,148,230 acres). This includes the cost of computer time ($250.00/hr.), materials, and personnel salaries and wages ($5.00/hr.; annual salary $10,400.00 without overhead) for the vegetation classification from LANDSAT MSS data, topographic data overlay, and geomorphic mapping. A necessary inclusion is personnel time for field work (vegetation and geomorphology), and data preparation for training statistics, spectral class descriptions, and evaluation. A per unit cost was $0.0386/hectare ($0.0156/acre), or $577.65 for one 7 1/2' U.S.G.S. quadrangle. If the size of the study area was significantly increased, the unit cost would be less; if the size of the study was significantly decreased, the unit cost would be greater.

When compared to the U.S. Forest Service figures (Table F. 7.) for a comparable Stage I - Stage II inventory of $1.70/acre or $1,951,991.00 for 1,148,230 acres, the benefit of computer-aided analysis of LANDSAT MSS data combined with topographic data overlay becomes apparent. Although the U.S. Forest Service figure appears to be high in comparison, many additional types of data inventory are also included, such as size and age classes. By utilizing base data, such as biomass and productivity, in conjunction with the resultant products

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of this study, a significant savings is realized. The actual time
necessary to complete this study (1.5 calendar years: 2 man-years) is
far less than that required by the procedures used by the U.S. Forest
Service (50 man-years).

Table.F.1. Time involvement by INSTAAR and LARS personnel on activities directly relating to the final products derived for the Southern San Juan Mountains Planning Unit.

Activity	Calendar Time	Number of People +	Total Personnel Time
Orientation	9 months	2	36 days
Training session – LARS	1 week	14*	70 days
Field work:			
vegetation	3 months	2	180 days
geomorphology	3 months	1	90 days
Vegetation:			
pre-processing		1	20 hrs.
training		3	100 hrs.
classification		1	1 hr.
spectral class descriptions (4 hrs./quadrangle)		1	120 hrs.
evaluation			
selection and transfer of test fields			
field work			70 hrs.
homogeneous photointerpretation			18 hrs.
systematic photointerpretation			25 hrs.
line and column coordinates			80 hrs.
key punching and analyst			9 hrs.
tally			72 hrs.
hand calculations			25 hrs.

Table F.1 con't.

Activity	Calendar Time	Number of People +	Total Personnel Time
Geomorphology:			
Land Systems Inventory			
development and mapping		1	.45 days
LANDSAT mapping – general			
diazos – development and evaluation			30 hrs.
Resource data review and integration			
Drainage patterns			8 hrs.
Landslides			20 hrs.
Alluvial and glacial deposits			8 hrs.
Topographic data overlay – man-hours not determined by LARS. Figure is estimate			50 hrs.
Technology transfer			
workshops and meetings (not including orientation, letters, or phone calls)	2 years	2-3	approx. 40 days
reports	1 1/2 years	4-8 people	approx. 400 days

+ These figures are for LARS and INSTAAR personnel only. The time expended by U.S. Forest Service personnel is impossible to account for, but is gratefully acknowledged. This is especially true for the orientation, field work, and technology transfer phases.

* This figure includes six U.S. Forest Service personnel who traveled to Purdue University, West Lafayette, Indiana for the training session.

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Table F.2. Data preparation for analysis and evaluation of LANDSAT MSS
data for cover type classification. These figures are based
on time involvement for analysis of 404,000 hectares
(1,000,000 acres).

Activity	Time Involvement	
Field work:	180 days	
(3 months/person)		
Classification:		
pre-processing	20 hrs.	
training statistics	100 hrs.	
classification	1 hr.	
Total	121 hrs.	15.1 days
Spectral class descriptions	120 hrs.	15 days
(4 hrs./quadrangle)		
Evaluation:		
Automatic evaluation – narrow interpreta-		
tion of community classes		
selection and transfer of test fields		
field work	70 hrs.	
homogeneous photointerpretation	18 hrs.	
systematic photointerpretation	25 hrs.	
line and column coordinates	80 hrs.	
key punching and analyst	9 hrs.	
Total	202 hrs.	25.25 days
Manual evaluation – narrow, moderate, and		
broad interpretation of community classes		
selection and transfer of test fields		
field work	70 hrs.	
homogeneous photointerpretation	18 hrs.	
systematic photointerpretation	25 hrs.	
Count and tally	72 hrs.	
Calculations	25 hrs.	
Total	210 hrs.	26.25 days

Table F.3. Time involvement for data preparation and analysis for general geomorphic mapping for the Southern San Juan Mountains Planning Unit.

Activity	Time Involvement	
Diazo preparation		
Experimentation	16 hrs.	
Master diazo set production	8 hrs.	
Evaluation of combinations (not specific interpretations)	6 hrs. —	
Total	30 hrs.	3.75 days
Resource data review and integration		
Drainage Patterns	8 hrs.	
Landslides	20 hrs.	
Alluvial and glacial deposits	8 hrs.	
Total	36 hrs.	4.50 days
Geomorphic Mapping *.		
Drainage Patterns	32 hrs.	
Landslides	8 hrs.	
Alluvial deposits	6 hrs.	
Glacial deposits	4 hrs.	
Total	50 hrs.	6.25 days

* This does not include time spent integrating base data for comparison with LANDSAT derived maps.

Table F.4. Cost for materials directly used in various phases of vegetative, topographic, and geomorphic mapping of the Southern San Juan Mountains Planning Unit.

Vegetation
    Computer-compatible tapes $200
        (1 LANDSAT scene)
    Aerial photographs   732
        (NASA Mission 75-101)
    U.S.G.S. maps, printout maps, supplies   100

                Total $1,032

Topographic Data
    Dept. of Defense Mapping Agency
        topographic data tape. $39

General Geomorphic Mapping
    Diazo set - 1 LANDSAT frame
        positive and negative transparencies $18
        diazos for experimentaion   10
        diazos for master set   5.50

                Total $33.50

    LANDSAT standard products
        2 color composites (already composited) $24 *
        8 LANDSAT frames - transparencies   .48
        (Bands 5 & 7 - $3/transparency)

             Total $72

* Frames not already composited at EROS cost an additional $50 each.

Table F.5. Computer costs for analysis of LANDSAT MSS and DODMA topographic data. These figures are for the IBM 360 model 67 computer used by LARS at the established rate of $250/hr. (31 U.S.G.S. 7 1/2' quadrangles, 463,885 hectares or 1,148,230 acres).

	Time (Hours)	Cost
LANDSAT MSS computer-aided analysis		
pre-processing	3.84 hrs.	$960.00
training	3.61	902.50
classification	2.85	712.50
evaluation (1 interpretation)	0.30	75.00
Total	10.60 hrs.	$2,650.00
Topographic data overlay		
registration to LANDSAT data	8.68	$2,171.00
slope and aspect calculation	0.54	136.00
merge run plus ten combinations	2.77	693.00
Total	11.99 hrs.	$3,000.00

Total computer costs for LANDSAT MSS classification and topographic overlay.

$0.012/hectare

$0.0049/acre

$182.258/ 7 1/2' quadrangle

Table F.6. Overall cost analysis for final products derived for
Southern San Juan Mountains Planning Unit (31 U.S.G.S.
7 1/2' quadrangles, 463,885 hectares, or 1,148,230 acres).

	Time	Cost
LANDSAT MSS analysis - Vegetation		
personnel time	261.6 days	$10,464.00 *
computer time	10.60 hrs.	2,650.00
materials		1,032.00
Total		$14,146.00
Topographic data overlay		
personnel time (estimated)	6.25 days	$250.00 *
computer time	11.99 hrs.	3,000.00
materials		39.00
Total		$3,289.00
Subtotal (vegetation and topography)		$17,435.00
Geomorphic mapping		
personnel time	10.0 days	$400.00 *
materials		72.00
Total		$472.00

Overall cost for study including vegetation classification, topographic
overlay, and geomorphic mapping.

   $0.0386/hectare

   $0.0156/acre

   $577.65/ 7 1/2' quadrangle

   $17,907.00/Southern San Juan Mountains Planning Unit

* Based on salary of $5.00/hr., or $10,400.00/year without overhead.

Table F.7. Comparison of time and cost between U.S. Forest Service conventional methods and LANDSAT data analysis. The LANDSAT analysis figures were derived from this study (Tables F.1-F.6), and the·U.S. Forest Service figures were derived from the proposed 1978 fiscal year ·budget for the Rio Grande National Forest.

	TIME		COST	
	U.S. Forest Service Conventional Methods	LANDSAT Analysis	U.S. Forest Service Conventional Methods	LANDSAT Analysis
Vegetation Analysis	Stage I-60% accuracy level 1,000,000 acres 15 man-years	79.8% accuracy level	Stage I $0.50/acre $574,115/study area	
	Stage II-80% accuracy level 1,000,000 acres 50 man-years	261.6 man-days	Stage II $1.20/acre $1,377,876/. study area	Stage I-II $1.70/acre $1,951,991/ study area — $0.012/acre $14,146/study area
Data Overlay	90 man-days	6.25 man-days	$0.017/acre $20,000/study area	$0.0028/acre $3,289/study area
Combined--. · Vegetation Analysis and Data Overlay	50 man-years (minimum time due to overlapping nature of Stage I- Stage II inventories)	2 man-years	$1.717/acre $1,971,991/study area	$0.0151/acre $17,435/study area
Geomorphic Mapping	Not available	10 man-days	Not available	$472
			Total for Study	$0.0156/acre $17,907/study area

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U.S. FOREST SERVICE APPLICATIONS

The cooperation and interaction of INSTAAR-LARS-USFS personnel has affected technology transfer to direct applications of LANDSAT MSS data. Numerous informal meetings served to explain the products, how they were derived, and the use of the multiple source data tape. These meetings and formal presentations of the results of this study to the Regional Office and the cooperating National Forests led to brain storming sessions where ideas were suggested concerning many phases of Forest Service responsibility. Some of the ideas had been tested in previous investigations and were workable. Others had been found to be not feasible. Some untried ideas were considered possible. The application of LANDSAT MSS data to these ideas has only begun.

> We feel that LANDSAT data can be used on land use planning, in various types of short range and long range functional project planning and, in time, will be useful in helping to determine accomplishment in the various functional areas and projects. These functional areas and projects include wildlife habitat, timber management, domestic livestock range, watershed management, avalanche area determination, transportation system location and others. (Bond, May 1976, personal communication; see Appendix C)

> Your thoughts concerning the various combinations of vegetation with topographic features are exactly the kind of opportunities where we can make the most use of the products you offer. It is now our (Forest Service) responsibility to determine the most logical combinations that will mean something to us for land use planning purposes and project purposes. With the number of combinations that exist and the rapid flexibility of making different combinations, we should be able to come up with those that are most significant. Assuming that we will continue to use soils information on an overlay basis, we could then construct a map using a good combination of vegetation-topographic features with a soils overlay and really pinpoint the good, medium, and/or poor sites for project proposals. (Cook, May 1976, personal communication; see Appendix C)

Mr. Dave Cook, wildlife biologist for the San Juan National Forest, requested a printout showing a specific combination of parameters which typified big game winter range. When he was not satisfied with the product, he took advantage of the flexibility of the overlay data tape to request a new combination of parameters.

After looking at the thematic map, I believe we should have many different parameters than those listed. For slope percent — 10 to 80 percent, broken down in 20 percent categories. On aspect, we should have 135° to 315°. On elevation, we need from 6000' to 9000'. And on vegetative types, we should have ponderosa pine-oakbrush, oakbrush-mixed browse, and all grassland types. By using this set of parameters, we can identify the areas that produce forage for big game animals and the areas that are most snow-free because of aspect, slope, and elevation. To identify this set of parameters using the conventional methods would require at least four overlays and the manual combination of these. The tabular data is useful in that when combined with the map, it indicates where certain types are located, the acreage of same, and then the percentage of the total area that is actually producing forage. The Forest Service presently has a generalized map of the big game winter range. With this kind of overlay, we can pinpoint the areas of actual use and ascertain the percent of the total area that is used. This kind of information will be extremely helpful when considering the impacts of certain project proposals such as timber sales, intensive range management practices, ski area development, etc. (Cook, May 1976, personal communication; see Appendix C)

The U.S. Forest Service uses various levels of resource inventory data. Stage I and Stage II are two distinct levels of inventory having separate objectives. Stage I survey is a basic extensive inventory which furnishes the management planner with general data of area and volume, condition classes, site and yield class indicies. From this information the management planner can make an overall evaluation of the condition and needs of a broad area to develop management objectives. The Stage I survey indicates how much and what, but generally does not pinpoint specific locations. Stage II inventory provides information as to the condition of specific stands, where they are located, and what action is needed to bring each stand into acceptable condition. Stage II inventories are compatible with and supplimental to Stage I inventories.

The estimated accuracy of Stage I is about 60% and costs about $.50 per acre. With a team of four people, it took almost three years to go from the photointerpretation phase to the data processing phase for 323 hectares (800,000 acres). This is an expenditure of $400,000. Stage II inventory costs $1.20 per acre to develop the information through the data process phase for permanent record. In

the Rio Grande National Forest a team of four people completed a Stage II inventory for 2,706 hectares (6,700 acres) of timbered land in three months. This is an expenditure of $8,040. For 404,000 hectares (1,000,000 acres) the projected cost would be $1,200,000 and would take 50 man-years to complete.

The vegetation classification of this study cuts across the information content of Stage I and Stage II inventories. The forest emphasis maps and tabular data derived from this classification are considered by the U.S. Forest Service to be more accurate (79.8%) than the Stage I inventory. By combining slope and aspect data with the vegetation classification using the user oriented combination program, the U.S. Forest Service feels the Stage II inventory could be done with similar accuracy (approximately 80%) in one half the field time because they could work with the computer maps to locate the stands of interest. This essentially eliminates much photointerpretation and transfer of data from one photo to a map, then changing map scales transfer the data to the final resource map. Second, the combination computer map more accurately locates those stands having less than a 40% slope. This is the "rule-of-thumb" cut off point for logging operations with conventional equipment or unconventional or high lead (elevated cable) or skyline (helicopter) operations. Third, these products give the forester information on stand homogeneity type, location, and tabulation of area to make determinations on the number of points to put into a stand. These products, if used properly with additional inventory data and with sound judgment, could significantly reduce field time while maintaining comparable accuracy (Lynn, personal communication; see support letters, Appendix C).

A specific application of the products generated during this study effectively illustrates the influence such products might have at the Project Level for the U.S. Forest Service (Lynn, personal communication; Appendix C). The area between the Alamosa and Conejos Rivers has few roads but contains a vast bank of resources. The first step is to determine what those resourses are, where they are located, and how much is there. The specific problem at the Project Level is to select areas for timber sales and to plan for the type of harvest and location of

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transportation corridors. The present system in use requires that the timber types be transferred from a 2"-to the mile map to the 7½' U.S.G.S. quadrangle. Next would be to determine, very subjectively, the slope aspect. The next step would be to manually combine slope aspect and timber overstory type to develop a map showing the location of timber resources on slopes greater than 40% and less than 40%. The accuracy of this manually derived product is estimated at 40%. An average of $20,000 per year is spent by one National Forest to do this type of overlay.

Bob Lynn, District Ranger for the Alamosa distict of the Rio Grande National Forest, requested printout maps for six quadrangles containing proposed timber sales. Three maps were generated for each quadrangle showing aspen, mixed forest, and spruce/fir on 0-30%, 30-45% and greater than 45% slopes (Fig. D.10 – D.12). These maps were used in the field during the summer of 1976 in preparation for the 1981 timber sales.

The next pahase is to do a transportation corridor analysis showing all possible alternative routes into the area. Once the corridor analysis is completed, the alternative routes need to be overlaid on the topographic map showing timber resources on the slope categories. Then an evaluation of the timber resources that can be served by each alternative route is made. The time required to do this is proportionate to the size and complexity of the area being analyzed. Upon completion of this phase a decision can be made as to the most economical transportation route when comparing road building costs ($30,000/mile) to the dollar return from the timber sale.

> The combination of the forest emphasis map (LANDSAT classification) with slope-aspect allows the forester to do a better quality job in shorter time, for completion of State II inventory ...and in knowing more specifically the areas to be flagged and marked, and in knowing what road system is needed to serve the block. I feel very strongly that using this method will reduce the total number of roads (road miles), allow us to build the needed roads to the proper standards so that they can handle industrial as well as recreation traffic safely and adequately for some time to come. Finally, I think it can also be shown that the impacts and effects on the soil and water resources will be reduced in the long run.

> I would like to take a few minutes to look in retrospect at the progress we have made toward the application of LANDSAT MSS data to the forestry field. As we began the interaction between your staff and the Forest Service personnel, we went through a

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perplexing period where both parties were struggling with the concepts, first to find out what LANDSAT could do and second how it could have application in the forestry field. In the first · several months of the project, many ideas surfaced. Some of the ideas were handled very quickly with outstanding results. To mention a few of these (there are) the completion of the mass stability mapping for the Chama River, the development of the methodology and final product of a landtype association-soil inventory of the planning unit. Another benefit for the effort is the continuous education of the Forest Service personnel about LANDSAT.

Of course, many of the ideas were for more advanced utilization of LANDSAT data which until lately we were not able to handle. However, I feel significant advances have been made in the practical application of this data to forestry. Within the last month (May 1976) we have finally arrived at a point where some of the ideas can be tested. I wish we had additional time to carry more of the ideas through with sufficient time to critique our efforts in terms of increased quality, accuracy and cost effectiveness. I hope that you (Dr. P. V. Krebs) will take the time to portray our efforts and accomplishments to the NASA Goddard staff. (Lynn, May 1976, personal communication; see Appendix C).

AUTHOR IDENTIFIED SIGNIFICANT RESULTS

The overall objectives of this project involved the application of computer-aided analysis techniques using LANDSAT MSS data to the mapping and acreage tabulations of forest cover types for 404,000 hectares (1,000,000 acres) study area designated as a major U.S. Forest Service planning unit, and to demonstrate the application of manual image interpretation of LANDSAT MSS data to mapping geomorphic features of the planning unit. As the study progressed, U.S. Forest Service personnel formulated many ideas which extended the activities beyond the original scope of the project of applying, LANDSAT MSS data analysis to the long-range planning process. The detail and flexibility of the resource information derived from this study has provided a data base for day-to-day management. Several observations and developments of major significance have occurred during the project activities which led to an increase of the awareness of remote sensing technology and the direct use of the resultant products.

The additional refinement of the modified cluster technique has clearly indicated the value of this analysis approach for effective mapping of forest cover types in areas of rugged mountainous terrain. A vegetation classification was successfully completed for 404,000 hectares (1,000,000 acres) derived from computer-aided analysis techniques applied to LANDSAT MSS data. At the request of the U.S. Forest Service this vegetation classification was then extended to an additional 90,900 hectares (225,000 acres) adjacent to the original study area. This added area is another planning unit for which the long-range planning process is to be initiated in Fall 1976. The evaluation of the vegetation classification based on the number of correctly classified pixels out of a total of possible number of pixels in the test fields was 84.4% at the generalized vegetation level and 79.8% at the community level.

Results of the vegetation classification derived from LANDSAT MSS data definitively illustrate that the same spectral classes in different geographic locations correspond to totally different cover

types (informational classes). That is, the same spectral response may be obtained from different categories of cover types located in different geographic areas. In this particular study area of mountainous terrain, the informational classes associated with some spectral classes changed from one 7 1/2' U.S.G.S. quadrangle to the adjacent quadrangle. This clearly indicates a need for further work in spectral stratification.

To provide a usable format of the final products, the LANDSAT data was rotated to a north orientation using a geometric correction procedure. This also was necessary to register the topographic data with the LANDSAT data. In future registrations it is recommended that the LANDSAT data be precision corrected to a geographic coordinate grid so that the output products will accurately match standard maps. The computer cost to do such geometric corrections adds significantly to the overall cost to provide products in a usable format for the user community. When other resource data is to be combined with LANDSAT derived information, geometric correction of LANDSAT data is essential.

Significant advances were made in deriving a multiple source data tape containing topographic data and vegetation classification results of LANDSAT MSS data. The multiple source data tape includes the vegetation classification of 25 spectral classes, elevation in 100 m increments, slope aspect in 12 categories, and percent of slope in 8 categories. The format was designed to be more suitable to user needs, and the data tape is being converted into the format of the R-2 and R-3 mapper programs of the U.S. Forest Service. Additional data sets, such as soils or land ownership, may be added by the U.S. Forest Service. The ability to generate in line printer output (scale 1:24,000) combinations of classification results and topographic data as selected by the various resource managers has been viewed as a valuable planning tool for the U.S. Forest Service. The selected combinations contain only the information of interest and value to address a particular problem. The flexibility to recombine the information in varied ways for problems having totally different interests increases the usefulness of the system. The data can be summarized in tabular format for

area and percentage for each combination.

LANDSAT MSS data was evaluated for landform mapping in general and within the system used by the U.S. Forest Service. This resulted in the development of manual analysis techniques applicable to current planning efforts.

The initial work emphasized the U.S. Forest Service classification of the Land Systems Inventory and focused on the landtype association level and the landtype level, the level of next greater detail. The landtype mapping categories would provide a data base for some land use decisions which could not be made with the landtype associations. Categories at the landtype level for the study area were defined (not previously done by the U.S. Forest Service) and were mapped using low-level aerial photographs. LANDSAT MSS images were then evaluated as a mapping tool for both landtypes and landtype associations.

Because of the limitations of the landtype and landtype associations, additional evaluation of LANDSAT MSS data focused on the use of images as a tool for geomorphic studies in general. Features analyzed during this phase of the project often relate to specific aspects of the Land Systems Inventory but were not restricted to the confines of the system itself. Although methods were developed and evaluated using specific geomorphic features, these techniques can be readily applied by U.S. Forest Service personnel to other fields of interest within the planning structure.

LANDSAT MSS data were evaluated for the feasibility for mapping the following geomorphic features: 1) landslides, 2) glacial deposits, 3) bottomland features including floodplains and alluvial fans, and 4) drainage patterns as an indicator of the underlying geology and for possible hydrologic inventories. Standard products rather than computer enhanced products were emphasized because they are readily available, inexpensive, and more versatile for manual interpretations. The methods employed and analyzed include stereo modeling, snow enhancement, stereo reversal, seasonal combinations, and diazo color composites.

The computer costs ($250.00/hr.) excluding personnel salaries and wages, for the vegetation analysis of LANDSAT MSS data and the topographic data overlay were $0.012/hectare ($0.0049/acre). Converting this figure, the computer cost to derive the data base for one 7 1/2'

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U.S.G.S. quadrangle was $182.26. The computer time includes pre-
processing and geometric correction, development of training statis-
tics, classification, evaluation, topographic data registration to
the LANDSAT MSS data, slope and aspect calculations, and merge run
plus ten combinations.

The overall cost analysis for the final products derived for the
Southern San Juan Mountains Planning Unit was $17,907.00 (463,885
hectares or 1,148,230 acres). This includes the cost of computer
time ($250.00/hr.), materials, and personnel salaries and wages
($5.00/hr; annual salary $10,400.00 without overhead) for the vegeta-
tion classification from LANDSAT MSS data, topographic data overlay,
and geomorphic mapping. A necessary inclusion is personnel time for
field work (vegetation and geomorphology) and data preparation for
training statistics, spectral class descriptions, and evaluation.
A per unit cost was $0.0386/hectare ($0.0156/acre), or $577.65 for
one 7 1/2' U.S.G.S. quadrangle. If the size of the study area was
significantly increased, the unit cost would be less; if the size
of the study area was significantly decreased, the unit cost would be
greater.

References Cited

Anuta, P. E. 1970. "Spatial Registration of Multispectral and Multi-temporal Digital Imagery Using Fast Fourier Transform Techniques," IEEE Transactions on Geoscience Electronics, Vol. GE-8, No. 4, pp. 353-368.

Anuta, P. E. 1973. "Geometric Correction of ERTS-1 Digital Multispectral Scanner Data," LARS Information Note 103073, LARS/Purdue University.

Anuta, P. E. 1975. "Computer-Aided Analysis Techniques for Remote Sensing Data Interpretation," LARS Information Note 100675, Purdue University.

Atwood, W. W., and Mather, K. F. 1932. Physiography and Quaternary geology of the San Juan Mountains, Colorado. U.S. Geological Survey, Pro. Paper 166, 176p.

Bingler, E. C. 1968. Geology and mineral resources of Rio Arriba County, New Mexico. New Mexico Bureau of Mines and Mineral Resources, Bulletin 91, 158p.

Brock, T. 1974. Landtype association level--Southern San Juan Mountains Planning Unit. Dept. of Agriculture, U.S. Forest Service, Rio Grande National Forest, 24p.

Colton, R. B., Holligan, J. A., and Anderson, L. W. 1975. Preliminary map of landslide deposits, Durango 1° X 2° quadrangle, Colorado. U.S. Geological Survey, Map MF-703.

Fleming, M. D., Berkebile, J. S., and Hoffer, R. M. 1975. "Computer-Aided Analysis of LANDSAT-1 MSS Data: A comparison of Three Approaches, Including a 'Modified Clustering' Approach", Machine Processing of Remotely Sensed Data Symposium Proceedings, Laboratory for Applications of Remote Sensing, W. Lafayette, Indiana.

Hoffer, R. M., Fleming, M. D., and Krebs, P. V. 1974. Use of computer-aided analysis techniques for cover type mapping in areas of mountainous terrain. LARS information note 091274, Purdue University, West Lafayette, Indiana, 14p.

Hoffer, R., and Staff 1975. "Natural Resource Mapping in Mountainous Terrain by Computer Analysis of ERTS-1 Satellite Data," Research Bulletin 919, Laboratory for Applications of Remote Sensing and Agricultural Experiment Station, Purdue University, W. Lafayette, Indiana, 124p.

Larsen, E. S., and Cross, W. 1956. Geology and petrology of the San Juan Region, Southwestern Colorado. U.S. Geological Survey, Prof. Paper 258, 303p.

Loranger, S. 1976. Landtype analysis in the Southern San Juan Mountains (unpub. M.A. thesis). University of Colorado, Boulder, Colorado.

Noma, A. A. 1974, "Toward Creation of a Digital Terrain Data Base," presented at American Society of Photogrammetry Convention, March 10-15, 1974, St. Louis, Missouri (paper available from author at Defense Mapping Agency Topographic Center, Washington, D.C. 20315).

Parvis, M. 1950. Drainage pattern significance in air photo identification of soils and bedrocks. Phot. Eng., v. 16, p. 387-409.

Richmond, G.M. 1954. Modification of the glacial chronology of the San Juan Mountains, Colorado. Science, v. 119, p. 614-615.

Sinding-Larsen, R. 1974. "A Computer Method for Dividing a Regional Geochemical Survey Area into Homogeneous Subareas Prior to Statistical Interpretation". Geological Survey of Norway, Trondheim, Norway.

Smeedes, H. W., Pierce, K. L., Tanguay, M. C., and Hoffer, R. M. 1970. "Digital Computer Terrain Mapping From Multispectral Data," Journal of Spacecraft and Rockets 7(9): 1025-1031.

Steven, T. A., Lipman, P. W., Hail, W. J., Jr., Barker, F., and Luedke, R. G. 1974. Geologic map of the Durango quadrangle, southwestern Colorado. U.S. Geological Survey, Map I-764.

Warrington, P. and Ryerson, R. 1974. Using diazo colour composites to extract information from ERTS-1 multispectral data. Second Canadian Symposium on Remote Sensing, University of Guelph, Guelph, Ontario, Canada; Proceedings, V. 1, p. 290-294.

Way, D. S. 1973. Terrain Analysis. Dowden, Hutchinson & Ross, Inc., Stroudsburg, PA. 392p.

Weber, W. A. 1972. Rocky Mountain Flora, University of Colorado Press, Boulder, Colorado, 437 p.

Wertz, W. A., and Arnold, J. F. 1972. Land systems inventory. Dept. of Agriculture, U.S. Forest Service, Intermountain Region, Division of Soil and Water Management, Ogden, Utah, 12 p.

APPENDIX A

SUPPLEMENTAL INFORMATION FOR USE OF
VEGETATION CLASSIFICATION DERIVED FROM
LANDSAT MSS DATA
A.1. LINE AND COLUMN COORDINATES
KEY TO TERMS USED IN APPENDIX A.2 AND A.3
A.2. SPECTRAL CLASS DESCRIPTIONS
A.3. SUGGESTED SPECTRAL CLASS GROUPINGS

The final product of this LANDSAT investigation is a results tape. This tape is on file at the U.S. Forest Service Computer Center in Ft. Collins, Colorado. The results tape contains one channel of elevation data in 100 meter increments, one channel of slope aspect data in 13 groups (north is split into two 7 1/2' groups), one channel of slope steepness data in 8 categories (see Section D), and one channel of the classification of LANDSAT MSS data for cover types (see Section C). This appendix supplies information about the spectral class data from the classification for people using the data on the results tape.

. To obtain a printout at a scale of 1:24,000 which is compatible with the U.S.G.S. 7 1/2' topographic maps, it is necessary to have the data printed on a line printer with 8 lines (vertical symbols) per inch, and 10 columns (horizontal symbols) per inch. To have maps which will fit directly over the 7 1/2' base maps it is important that the line and column coordinates listed in the table in Appendix A.1 be used. There are some lines or columns which are extra between quadrangles, and some areas of overlap between quadrangles. This is caused by the LANDSAT data being printed out in a rectangular format; and the longitude lines converging toward the poles, and latitude lines being slightly curved on a flat map. For each quadrangle in the planning unit for which a 7 1/2' base map was available, the base map was lined up with features on the logogramatic map, and line and column coordinates of the corner points determined. The line and column coordinates given reflect the best possible fit of LANDSAT data to the base maps.

Informational classes corresponding to each spectral class often changed from one quadrangle to another. Every spectral class on each quadrangle in the planning unit was defined separately using base maps, computer printout maps and aerial photographs in a stereo mode. This information is listed in Appendix A.2 for every quadrangle. For some work it is useful to have vegetation classes grouped in generalized categories, or in categories of forest or grassland emphasis. Suggested groupings for these categories based on the spectral class descriptions are given in Appendix A.3. A key to the short-hand used in the spectral class descriptions is located immediately before the spectral class descriptions in Appendix A.2.

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APPENDIX A.1

LINE AND COLUMN COORDINATES

Appendix A.1. Line and column coordinates for the 7 1/2' quad-
rangles in the Southern San Juan Mountains.

Quadrangle Name	First Line	Last Line	First Column	Last Column
Wolf Creek Pass NW	3	184	5	185
Wolf Creek Pass NE	3	184	186	366
Elwood Pass	4	185	368	548
Summitville	4	185	549	729
Jasper	5	186	730	910
Greenie Mountain	5	186	911	1091
Wolf Creek Pass SW	184	365	4	185
Wolf Creek Pass SE	185	366	186	366
Summit Peak	185	366	367	547
Platoro	186	367	548	729
Red Mountain	187	368	730	911
Terrace Reservoir	187	368	912	1093
Chromo NW	366	547	1	180
Chromo NE	367	548	185	365
Chama Peak NW	367	547	367	547
Chama Peak NE	368	548	548	729
Spectacle Lake	368	549	730	911
La Jara Canyon	367	548	912	1092
Vicente Canyon	368	549	1093	1274
Chromo SW	546	727	1	181
Chromo SE	546	727	182	362
Chama Peak SW	546	727	367	547
Chama Peak SE	548	729	546	727
Cumbres	549	730	729	910
Osier	549	730	911	1092
Fox Creek	549	730	1093	1274
Brazos Peak NW	731	912	730	911
Brazos Peak NE	731	912	912	1092
Bighorn Peak	731	912	1093	1274

Wolf Creek Pass NW L 3-184 C 5-185	Wolf Creek Pass NE L 3-184 C 186-366	Elwood Pass L 4-185 C 368-548	Summit- ville L 4-185 C 549-729	Jasper L 5-186 C 730-910	Greenie Mtn. L 5-186 C 911- 1091	Fulcher Gulch
Wolf Creek Pass SW L 184-365 C 4-185	Wolf Creek Pass SE L 185-366 C 186-366	Summit Peak L 185-366 C 367-547	Platoro L 186-367 C 548-729	Red Mtn. L 187-368 C 730-911	Terrace Res. L 187-368 C 912- 1093	Centro
Chromo NW L 366-547 C 1-180	Chromo NE L 367-548 C 185-365	Chama Peak NW L 367-548 C 367-547	Chama Peak NE L 368-548 C 548-729	Spectacle Lake L 368-549 C 730-911	La Jara Canyon L 367-548 C 912- 1092	Vicente Canyon L 368-549 C 1093- 1274
Chromo SW L 546-727 C 1-181	Chromo SE L 546-727 C 182-362	Chama Peak SW L 546-727 C 367-547	Chama Peak SE L 548-729 C 546-727	Cumbres L 549-730 C 729-910	Osier L 549-730 C 911- 1092	Fox Creek L 549-730 C 1093- 1274
				Brazos Peak NW L 731-912 C 730-911	Brazos Peak NE L 731-912 C 912- 1092	Bighorn Peak L 731-912 C 1093- 1274

KEY TO TERMS USED IN
APPENDIX A.2 AND A.3

For the following pages showing spectral class descriptions and covertype groupings for each quadrangle, a type of shorthand has been developed for designating covertypes. The key given below should help explain the symbols used.

SF	Englemann spruce and subalpine fir together
DWF	Douglas fir and white fir together
DF	Douglas fir
PP	Ponderosa pine
PJ	Piñon pine and Rocky Mountain juniper together
A	aspen
0	Gambel's oak
cottonwood	narrow-leafed cottonwood
willow	either alpine willow or riparian willow
/	indicates the species to the left and right of the slash occur together as a mix
w/	with
,	indicates that additional comments about the covertype follow
;	indicates that a new covertype occurrence is to be listed. May refer to a whole new covertype or different density or composition of one previously listed.
:	used in species composition listing – see species composition
or	indicates another species which may be present
or	indicates whole new covertype for a spectral class
and/or	indicates that one or both species may be present

Density indications –

100%	crown closure 100% – no ground visible from directly overhead
50%	50% crown closure, 50% ground visible from directly overhead
50-70%	crown closure of species listed varies from 50% through 70%. Other percentages listed this way also indicate varying crown closures.

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Species composition indications –

> The species in a mix are listed first, the most dominant
> to the left of the slash. The numbers following indicate
> the relative density of each in the total mix. The num-
> ber to the left of the colon corresponds to the dominant
> species on the left of the slash; the number on the right
> of the colon corresponds to the species listed to the
> right of the slash. Multiply the numbers by 10 to obtain
> the percentage of each; add the two numbers to find total
> crown closure for the stand. All crown closures and
> species density figures are based on a possible 100%
> crown closure.

Example:

> SF/A   7:2
> This is a mixed forest with Englemann spruce and subalpine
> fir having 70% crown closure, and aspen having 20% crown
> closure; the entire stand has a crown closure of 90%.
>
> Some mixed forests have a range of species composition.
> This is usually indicated as follows:
>
> > SF/A   7:3 – 3:7
>
> This means that the mix forest has all compositions of
> spruce/fir and aspen from predominantly coniferous, to
> half and half, to predominantly deciduous. This will
> also incorporate total crown closure of less than 100%
> for the stand.

SF,DWF/A,O

> indicates that spruce/fir and/or douglas fir/white fir
> are mixed with aspen and/or oak.

SF/A 7:3; 5:2

> indicates two different species compositions were found
> when describing spectral classes: one stand of spruce
> fir having 70% crown closure occurring with aspen having
> 30% crown closure; and another of spruce/fir having 50%
> crown closure occurring with aspen having 20% crown closure.

APPENDIX A.2

SPECTRAL CLASS DESCRIPTIONS

WOLF CREEK PASS NW - Spectral Class Descriptions

A water; shadow - aspen or bare rock

B DWF or SF 90-100%

C DWF 70-90%

D DWF 70-80%, may have < 10% aspen

E,F DWF/A 7:3-3:7

G snow covered on aerial photo, probably SF krummholz

H krummholz 30%; blue spruce/cottonwood 2:2

I

J snow covered, appears to be meadow w/< 40% conifer

K aspen 100%

L aspen 70-90% (patchy)

M,N aspen 100%

O dry meadow w/patchy aspen and PP < 20%

P mesic meadow or tundra

Q tundra - snow covered, may have willows; wet meadow
   w/willows

R

S wet meadow - watered by snow banks or irrigated

T tundra- snow covered, probably dry but not rocky

U mesic to dry tundra w/rocks

V bare rock; sparsely vegetated

W bare rock

X,Y bad data

WOLF CREEK PASS NE. — Spectral Class Descriptions

A   water.

B   SF 90-100%

C   SF 80% (slight aspen)

D   DWF/A 5:3; DWF, SF/aspen 7:3

E   DWF/A 5:5.

F   A/SF 5:5

G   DWF 70% w/rocky meadow

H   SF <40%; Pinus pseudostrobus <20% w/meadow.

I.

J   sparse aspen; sparse conifer with rock; DWF/aspen 5:5

K   aspen 100%.

L   aspen 100%

M   aspen 100% ; aspen 80% w/ <10% DWF

N   aspen 100% with patchy meadow

O   young aspen <80%; patchy aspen 60% w/meadow.

P   meadow/shrub/cottonwood; old logging – meadow/shrub

Q   wet meadow w/willow; meadow w/shrub

R   meadow w/sparse aspen

S   wet meadow

T   wet meadow

U   dry meadow and tundra

V   bare rock, sand bars

W   bare rock

X,Y   bad data.

ELWOOD PASS – Spectral Class Descriptions

A   water

B   SF.100%

C   SF 70-90%; SF/A 9:1

D   SF/A 7:3; 6:2

E,F SF/A 8:2-2:8

G,H SF <50% – sparse timber, clear cut

I   dry rocky tundra; clear cut logging

J   aspen 80-100%; SF/aspen 4:3 w/rocks

K

L   wet meadow w/willows; aspen 70-90%

M   aspen 80-100%

N   aspen 80-100%

O   aspen/SF 6:2

P   stress site aspen <50% w/rocks and dry meadow

Q   wet tundra

R   aspen 100%

S   wet tundra

T   mesic tundra

U   mesic tundra w/SF krummholz <10%

V   sparsely vegetated, rocky tundra

W   bare rock

X,Y bad data

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SUMMITVILLE - Spectral Class Descriptions

    A   water; shadow

    B   SF 100%

    C   SF 90%; SF/A 7:2

    D   SF 70-100%; SF/A 8:1

    E

    F   A/SF 7:3

    G   SF 50-80%; krummholz

    H   SF <30%

    I   dry tundra

    J   aspen 70-100%

    K

    L

M,N   aspen 100% - patchy

    O   aspen 100%

    P   aspen 50%; aspen 70-90%

    Q   wet tundra; aspen 100%; aspen 50%; wet meadow
         w/willow

    R   aspen 100%

    S   wet meadow

    T   moist tundra

    U   dry tundra

    V   dry rocky tundra

    W   bare rock

X,Y   bad data

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JASPER - Spectral Class Descriptions

A   water; shadow - SF 50-80% w/avalanche tracks and rocks

B   SF 90-100%

C,D   SF 80-100% w/ <20% aspen

E

F   aspen/SF 8:2-6:4

G   SF 40-70%, selectively logged; DWF 40-60% w/rocks

H   SF or DWF 30-50%

I   clear cut logging - slash and grass

J   A/SF 4:1; aspen 80-100% w/small meadows

K   aspen 100%

L   aspen 100%

M   aspen 80-100%

N   aspen 80-100%

O   aspen 100%

P   meadow w/aspen <40%; tundra

Q   mesic tundra, snow covered-may have willows; aspen <50%
    w/meadow

R   aspen 80-100% w/ meadows

S   irrigated meadow

T   mesic tundra, krumholz <20%

U   mesic tundra

V   sparse tundra - rocky

W   bare rock

X,Y   bad data

GREENIE MOUNTAIN – Spectral Class Descriptions

A

B   DF 90-100%

C   DF 80-90%

D   DF, PP 80-90% w/Aspen 10%

E   A/DF 9:1-6:4

F   A/DF 10:0-8:2

G   PP, DF 50-80%

H   PP <50% w/grass and sage

I   PJ 40-60%

J   aspen 80-100%; aspen/DF,PP 7:3 (patchy)

K

L

M

N

O   aspen 70-100%

P   mesic-dry meadow

Q   aspen 40-70% w/dry meadow

S

T

U   mesic-dry meadow

V   dry meadow w/sage, PJ, PP, and DF <10%

W   sparsely vegetated, dry meadow

X,Y   bad data

WOLF CREEK PASS SW - Spectral Class Descriptions

A

B DWF 80-100%

C DWF 70-90%

D DF/A 8:2-6:4

E DF/A 8:2-6:4

F PP/O 5:5 - 5:2

G PP 50% w/grass

H PP 20-40% w/grass

I dry meadow

J oak 60-100%, PP< 10%

K aspen 100%

L aspen 80-100% w/patchy meadow

M aspen 80-100%

N aspen 100%

O meadow w/oak or shrub; PP/O 4:3

P mesic - dry meadow, PP/O<30%

Q wet meadow w/willows

R wet meadow

S irrigated pasture

T

U dry meadow

V dry meadow

W sparsely vegetated

X,Y bad data

WOLF CREEK PASS SE – Spectral Class Descriptions

A   shadow

B   SF 90–100%

C   SF 80–100%

D   SF 80–100%; SF/A 6:2 – 8:2

E,F   SF/A 7:3–3:7

G   SF 50–70% w/rocks

H   clear cut – grass and slash, SF <20%

I

J   SF/A 6:2

K   aspen 80–100% (SF <10%)

L   aspen 100%

M   aspen 100%

N   aspen 100%

O   A/SF 6:4 – 5:5 – 4:6;   O/PP 4:2 – 4:4

P   aspen (stunted) <40% w/rocky meadow

Q   tundra (snow covered on aerial photography)

R

S   irrigated pasture

T   dry tundra

U   tundra (snow covered on aerial photography)

V   bare rock

W   bare rock

X,Y   bad data

SUMMIT PEAK – Spectral Class Descriptions

A   water; shadow – bare rock

B   SF   100%

C   SF 90–100%

D   SF 70–100%; SF/A 8:2

E   A/SF 4:4

F   SF 50–70%, sometimes with aspen <30%

G   SF   60%– krummholz

H   krummholz

I   rocky tundra

J   aspen 50% w/meadow

K

L

M

N

O   snow covered–appears to be aspen 50% w/meadow

P   meadow–snow covered

Q   snow covered–appears to be wet meadow w/willow

R   meadow–snow covered

S   tundra–snow covered

T   wet meadow and tundra

U   meadow–snow covered

V   bare rock; sparsely vegetated

W   bare rock

X,Y   bad data

PLATORO - Spectral Class Descriptions

A   water; shadow - sparse conifer

B   SF 90-100%

C   SF 70-90%

D   SF 60-80% w/grass, sometimes aspen <10%

E,F SF 40-60% - old logging; A/SF 7:3-3:7

G   sparse conifer w/rocky meadow; includes bristlecone

H   SF <30% w/rocks and rocky meadow understory

I   rocky tundra

J   dry meadow w/shrub; aspen 100%

K

L   aspen 80-100%

M

N

O   young aspen w/willow; aspen 60-70% w/meadow

P   dry meadow w/conifer <20% or aspen <40%

Q   wet meadow w/willows; dry meadow w/aspen <30%

R

S

T   dry rocky tundra

U   dry meadow

V   sparsely vegetated tundra

W   bare rock

X,Y bad data

RED MOUNTAIN - Spectral Class Descriptions

A water; shadow - DF <60% and bare rock

B SF, DF 100%

C SF, DF 90-100%

D SF, DF 70-90% w/aspen 10%

E DF/A 6:4-4:6

F A/DF 6:2-8:2

G DF, SF 40-70% w/rocks

H SF 30-50%

I dry meadow

J sparse stunted aspen 40-80%, rocky meadow understory

K

L

M aspen 80-100%

N

O aspen 100%.

P mesic-dry meadow and tundra

Q mesic tundra and meadow

R aspen 60% w/meadow (patchy); aspen 80-100%

S

T mesic tundra w/willows; dry meadow w/shrubs

U mesic-dry tundra and meadow

V dry rocky tundra

W snow covered-appears to be bare rock or sparsely
vegetated tundra

X,Y bad data

TERRACE RESERVOIR – Spectral Class Descriptions

A   water

B   DF, SF 100%

C   DF/A 9:1

D   DF/A 8:2-7:1; DF 70-80%, may include some PP

E,F   A/DF, PP 8:2-2:8; includes mixes 50-70% total

G   PP 40-60%; PP/A 5:3

H   PP/A 4:2; DF 60%; PJ 40%; PP 30-50% w/grass

I   dry meadow w/shrub; PP or PJ 20-40%; PP 30-50% w/ grass

J   aspen 70-100% (patchy)

K   aspen 100%

L

M

N

O   aspen 80-100%

P   wet meadow

Q   meadow w/willow

R

S

T   mesic meadow

U   mesic-dry meadow

V   dry meadow, may include sage

W   sparsely vegetated meadow

X   bad data

Y   water and bad data – LaJara and Terrace Reservoirs show
    as Y's; Y's in straight lines are bad data

CHROMO NW - Spectral Class Descriptions

A water

B DF 90-100% (aspen<10%)

C DF/A 7:3-8:2

D DF/A 5:3-6:4

E DF/A 5:5-7:3

F A/DF 5:5-8:2; O/PP 6:2-2:4

G PP 30-60% w/grass

H PP 20-60% w/grass

I mesic-dry meadow

J O/PP 6:1-3:3-3:4; oak 50%

K

L aspen 80-100%

M aspen 80-100%, includes some cottonwood

N aspen 80-100%

O O/PP 8:1-5:2; O/A 7:2-5:2

P dry meadow w/clumps of oak <30% and some sage

Q wet-mesic meadow w/willow or sage

R mesic meadow

S wet meadow

T

U mesic-dry meadow, sometimes PP/O 2:1

V dry meadow PP <10%

W sparsely vegetated, bare rock

X,Y bad data

CHROMO NE – Spectral Class Descriptions

A water; shadow – sparsely vegetated

B SF 80-100% w/avalanche chutes

C SF 70-90%

D DWF/A 8:2-6:4

E A/DWF 6:4 w/little ponds; A/DWF 8:2-6:4

F PP/O 5:3-3:5 w/dry meadow

G PP<50% w/grass

H PP<50% w/grass

I

J O/PP 5:2 w/meadow.

K aspen 100%

L aspen 100%

M aspen 80-100%; some cottonwood

N aspen 100%

O oak 80%; O/A 5:2-7:2 w/PP <10%

P wet meadow

Q wet-mesic meadow w/willow

R mesic-dry meadow

S mesic meadow; irrigated pasture

T mesic meadow.

U dry meadow

V sparsely vegetated meadow

W bare rock and bare soil

X,Y bad data

CHAMA PEAK NW – Spectral Class Descriptions

A   water; shadow-bare rock

B   SF 100%

C   SF 70-100%

D   DWF, SF/A 8:2-7:3

E,F A/DWF, SF 6:4-5:5-4:6

G   DWF 60%

H   SF (krummholz) 40%; cottonwood/blue spruce 70%

I   dry meadow

J   aspen 50-70%

K   aspen 60-80% (patchy); aspen 80-100%

L   aspen 100%

M   aspen 100%

N   aspen 100%

O   A/DWF 8:1-5:2

P   mesic tundra

Q   wet meadow w/willow

R   wet-mesic meadow

S   wet-mesic meadow and tundra

T   dry tundra

U   dry tundra

V   sparsely vegetated, rocky meadow

W   bare rock

X,Y bad data

CHAMA PEAK NE - Spectral Class Descriptions

A   water; shadow - SF <50% and bare rock

B   SF 90-100% w/avalanche chutes

C   SF 90-100%; shadow-bare rock.

D   SF 80-100%

E,F   SF/A 6:4-4:6

G,H   wet meadow; sparse SF <40%

I

J   meadow w/sparse aspen and SF

K

L

M   aspen 90-100%

N   aspen 80-90% (patchy meadows)

O   aspen 50% w/scattered SF

P   mesic tundra

Q   wet meadow w/willows

R   aspen 90-100%

S   wet meadow

T   mesic tundra and meadow

U   mesic-dry meadow

V   sparsely vegetated meadow or bare rock

W   bare rock

X,Y   bad data

There was not a 7 1/2' base map available for the Chama Peak
NE quadrangle. The descriptions were done by superimposing
the aircraft coverage onto the spectral class printout. The
lack of stero viewing, and difficulty of locating small patches
of pixels resulted in less detailed descriptions than is
available for the rest of the planning unit.

SPECTACLE LAKE - Spectral Class Descriptions

A water; shadow - rocky cliffs

B SF, DF   80-90%

C SF 80-90%

D DF, SF/A 8:2-5:2

E coniferous/A 5:5-7:3 (coniferous includes SF, DWF, PP)

F A/coniferous 5:5-7:3 (coniferous includes SF, DWF, PP
   and blue spruce, some cottonwood included w/aspen)

G PP 40-60% (aspen <20%)

H PP 20-40%

I dry meadow

J aspen 70-100% (patchy meadows); cottonwood 80-100% on
   floodplain

K aspen 100%

L

M aspen 80-100%

N

O cottonwood/willow

P meadow with shrub, willows, patchy aspen

Q meadow w/willow

R

S wet meadow; irrigated pasture

T

U dry meadow

V sparsely vegetated meadow

W

X,Y bad data

LA JARA CANYON – Spectral Class Descriptions

A water
B
C DWF 90%
D DWF/A 8:2-7:2
E A/DWF 5:5-6:4
F A/DWF, PP 8:2-5:2
G PP/A 4:2-4:3; PP, DWF 50-70%
H PP 20-50%; DWF/A 4:4; PP/A 4:1
I dry meadow w/PP or PJ <30%
J aspen 50-70%
K aspen 80-100%
L aspen 80-100%
M
N
O aspen 70-100%; cottonwood 80%
P mesic meadow
Q wet meadow, sometimes w/willow
R
S
T mesic-dry meadow
U dry meadow
V dry meadow, sometimes PP <10% or sage 40-80%
W sparsely vegetated meadow or bare rock
X bad data
Y water in LaJara reservoir; straight lines are bad data

VICENTE CANYON – Spectral Class DEscriptions

A

B

C   DF 70-90%

D   DWF/A 7:2

E

F

G   PP 70%

H   PP/PJ 60%; PP 30%

I   PP/PJ 50% w/dry meadow; PP, DF 60%

J

K

L

M

N

O

P   wet meadow

Q   wet meadow

R

S

T

U

V   sparsely vegetated, dry; some sage

W   bare rock

X,Y   bad data

CHROMO SW – Spectral Class Descriptions

A   water

B   DF 90–100%

C   DF 80%; DWF/A 7:3

D   DWF/A 7:2 – may include oak and PP

E,F   DWF/A 8:2–2:8; DWF, PP/A, O 5:3–3:5

G   PP 50–70% w/grass

H   PP 30–60% w/grass

I   dry meadow, PP <10%

J   PP/O 5:2–3:2

K   aspen 80–100%

L   aspen 80–100%

M   aspen 80–100%

N

O   oak 50–80%, sometimes PP <20%

P   mesic–dry meadow w/PP <10% or O/PP <50% (3:2 density)

Q   mesic meadow; irrigated field

R   aspen 80%; aspen/oak 8:2

S   irrigated field

T

U   mesic–dry meadow, sometimes oak <20%

V   dry meadow

W   bare rock; sparsely vegetated meadow

X,Y   bad data

CHROMO SE – Spectral Class Descriptions

A water

B

C

D DWF/A 6:4; PP/O 6:4

E,F DWF/A 7:3-3:7; O/PP 7:3-2:3

G

H PP 20-40%

I dry meadow

J oak 40-60%; oak/aspen 4:4

K aspen 100%

L aspen 100%

M aspen 100%

N aspen 100%

O oak 60-80%, sometimes w/PP <20%

P dry meadow, sometimes w/PP or oak <20%

Q irrigated meadow; O/PP 5:3-4:2

R

S irrigated meadow

T

U dry meadow

V dry meadow

W bare rock

X,Y bad data

CHAMA PEAK SW - Spectral Class Descriptions.

A water; shadow - SF <20% and bare rock

B DF 100%

C DF, SF 70-80%

D SF 60-80%; DF/A 6:4-8:2

E A/DF 8:2-6:4

F A/DF 8:2-6:4

G DF 60-70%

H cottonwood/blue spruce 50% w/gravel bar

I

J oak/aspen 4:3; cottonwood and aspen 70%

K aspen 100%

L aspen 100%

M aspen 100%

N aspen 100%

O aspen 50-70%; aspen/oak 4:3-5:5

P mesic meadow

Q wet meadow, sometimes w/willow

R aspen 60-80%

S irrigated pasture

T mesic-dry tundra

U tundra

V sparsely vegetated; bare rock

W bare rock

X,Y bad data

CHAMA PEAK SE – Spectral Class Descriptions

A   water; shadow

B   SF 100%

C   SF 90%, sometimes aspen <10%

D   SF 60-90%; SF/A 5:3-4:1

E,F   SF/A 7:3-5:5-3:7

G   SF 70-80%

H   dry meadow, w/sparse SF

I

J   aspen 50%; spruce <40%; dry rocky meadow

K   aspen 80-100%

L   aspen 80-100%

M   aspen 80-100%

N   aspen 50%; meadow

O   meadow; aspen 50% or SF 60%

P   wet meadow; clear cut logged

Q   wet meadow, sometimes w/willow

R   mesic meadow

S   mesic meadow

T   dry rocky meadow, sometimes SF <20%

U   dry meadow; dry rocky meadow

V   sparsely vegetated meadow

W   bare rock

X,Y   bad data

CUMBRES – Spectral Class Descriptions

A water; shadow – bare rock

B SF 90-100%

C SF 80-100%

D SF 50-80% selectively logged

E,F SF 40-70% selectively logged; SF/A 8:2-2:8

G

H clear cut logged – slash and grass

I dry rocky meadow, sometimes SF <10%

J aspen <30%; meadow

K aspen 80-100%

L aspen 70-90%

M aspen 100%; aspen 60-100% (patchy)

N aspen 60-100% (patchy)

O aspen 80-100%

P wet-mesic meadow; clear cut logging

Q wet meadow w/willow

R aspen 80-100%

S

T mesic-dry meadow

U snow covered-appears to be mesic tundra; meadow w/shrub

V sparsely vegetated rocky talus

W bare rock

X,Y bad data

OSIER - Spectral Class Descriptions

A

B DWF/A 7:3-6:2

C DWF/A 3:3-5:5; DWF 90% w/aspen <10%

D DWF/A 6:4-7:3 ; DWF, PP 60-80%

E A/DWF 6:4-7:3

F A/DWF 8:2-5:4

G DWF, PP, and/or SF 50-80%

H DWF, PP 40-60%

I dry meadow

J aspen 60-100%

K

L aspen 80-100%

M aspen 80-100%

N

O cottonwood/willow 50%; aspen 50-100%

P wet-mesic meadow

Q meadow w/willow

R

S

T :

U mesic-dry tundra; mesic meadow w/aspen or shrub <50%

V sparsely vegetated w/sage and rabbit brush, sometimes PP <10%

W sparsely vegetated dry meadow

X,Y bad data

FOX CREEK - Spectral Class Descriptions

A

B

C DWF, PP 80-90%; DWF/A 7:3-8:2

D DWF 60-80%; DWF/A 6:4-7:3

E,F DWF, PP/A 8:2-2:8; A/DWF 7:3-10:0

G PJ 20-40%; PP 70%; DWF 60%

H PJ 30-60%; PP 50-70%; PP 20-30%; DWF 40%

I dry meadow, sometimes PJ <20% or PP <20%; also agricultural

J cottonwood or aspen 60-80%

K aspen 80-100%

L cottonwood/meadow (patchy)

M aspen 80-100%

N

O aspen or cottonwood 60-100%

P wet-mesic meadow

Q wet meadow, sometimes w/willow

R

S irrigated pasture

T wet meadow

U mesic meadow; agricultural

V dry meadow; sometimes PJ <20% and/or sage

W sparsely vegetated dry meadow; some sage

X,Y bad data

BRAZOS PEAK NW - Spectral Class Descriptions

A water

B SF 90-100%

C SF, DWF 80-90%

D SF, DWF 70-80%

E A/SF, DWF 7:3-3:7

F sparse conifer w/shrub or aspen

G,H PP <40% w/shrub

I grassland w/shrub

J A/SF, DWF, PP 5:5-6:3; young aspen <60%

K aspen 100%

L aspen 100%

M aspen 100%

N aspen 100%

O A/SF, DWF, PP mix w/grass

P old logged; sparse conifer

Q wet meadow, sometimes w/willow; oak

R

S

T wet meadow; irrigated pasture

U wet-mesic meadow

V dry rocky meadow

W bare rock

X,Y bad data

There was not a 7 1/2" base map available for the Brazos
Peak NW quadrangle. The descriptions were done by super-
imposing the aircraft coverage onto the spectral class
printout. The lack of stero viewing, and difficulty of lo-
cating small patches of pixels resulted in less detailed
descriptions than is available for the rest of the planning
unit.

BRAZOS PEAK NE — Spectral Class Descriptions

A water

B. SF 90-100%

C SF 80-100%

D DWF 70-100%, sometimes w/aspen <10%

E. SF, DWF/A 8:2-6:4

F A/SF, DWF 8:2-7:3

G sparse SF, DWF <40% w/grass

H sparse SF, DWF <40% w/grass

I sparsely vegetated w/sage

J. aspen<70%

K aspen 80-100%

L aspen 100%

M aspen 100%

N aspen 100%

O young aspen 60-90%

P shrub/meadow; aspen <30% w/meadow

Q meadow w/willow or young aspen

R wet meadow; edge of meadow/aspen interface

S wet meadow; edge of meadow/aspen interface

T meadow

U. dry meadow

V sparsely vegetated meadow

W bare rock

X,Y bad data

There was not a 7 1/2" base map available for the Brazos Peak
NE quadrangle. The descriptions were done by superimposing
the aircraft coverage onto the spectral class printout. The
lack of stereo viewing, and the difficulty of locating small
patches of pixels resulted in less detailed descriptions than
is available for the rest of the planning unit.

BIGHORN - Spectral Class Descriptions

A

B

C DWF/A 9:1

D DWF/A 6:4-8:2

E PP/O 7:3; DWF/A 7:3

F O/PP 8:2-6:4; A/DWF 7:3

G PJ/oak 6:2 w/grass; PP/oak 6:2

H PJ <30% w/oak 40%; PP <30% w/grass

I dry meadow w/sage and rabbit brush

J aspen 70%; oak 60%

K aspen 80-100%

L aspen 80-100%

M aspen 100%

N aspen 100%

O young aspen <60%, sometimes PP or DWF <10%

P sparse DWF w/shrub and grass

Q wet meadow w/willow

R wet meadow w/shrub

S

T

U dry meadow

V sparsely vegetated meadow w/sage

W bare rock

X,Y bad data

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APPENDIX A.3

SUGGESTED SPECTRAL CLASS
GROUPINGS

WOLF CREEK PASS NW

Covertypes and Spectral Classes

Generalized:
water - A
coniferous - B, C, D, G, H
mix - E, F
deciduous - K, L, M, N
grassland - O, P, Q, S, T, U
bare - V, W

Forest Emphasis:
water - A
DWF, SF 90-100% - B
DWF, SF 70-90% - C, D
DWF/A 7:3-3:7 - E, F
SF ≤40% (krumholz) - G, H
aspen 70-90% - L
aspen 100% - K, M, N
mix <30% - O
grassland - P, Q, S, T, U
bare - V, W

Grassland Emphasis:
water - A
forest - B, C, D, E, F, K
grassland >60% w/SF - G, H
grassland 10-30% w/aspen - L
dry meadow >70% w/aspen, PP or SF - O
mesic meadow and tundra - P, T
wet meadow - S
dry tundra - U
sparsely vegetated - V
bare rock - W

Not well represented: I - prob dry rocky grassland
R - prob mesic meadow

Majority snow covered: G - prob SF <40% Krummholz
(difficult to describe) J - appears to be SF <40% w/grass
Q - appears to be meadow, maybe w/willows

WOLF CREEK PASS NE

Covertypes and Spectral Classes

Generalized:

water - A
coniferous - B, C, G, H, J
mix - D, E, F
deciduous - K, L, M, N, O
grassland - P, Q, R, S, T, U
bare - V, W

Forest Emphasis:

water - A
SF 90-100% - B
SF 70-90% - C
DWF/A 5:3-7:3 - D
DWF/A 6:4-4:6 - E, F
DWF <70% - G, J
SF <50% - H
aspen 100% - K, L, M, N
aspen 60-80% (young) - O
grassland - P, Q, R, S, T, U
bare - V, W

Grassland Emphasis:

water - A
forest - B, C, D, E, F, K, L, M, N
grassland 30-80% w/conifer - G, H, J
grassland 20-40% w/aspen-O
meadow w/shrub (willows) - Q
meadow w/shrub and slash (logged) - P
wet meadow - S
mesic meadow - R, T
dry meadow and tundra - U
sparsely vegetated (<50% grass) - V
bare rock - W

Not well represented: I - prob dry meadow

ELWOOD PASS

Covertypes and Spectral Classes

Generalized: water - A
                        coniferous - B, C, G, H
                        mix - D, E, F, O
                        deciduous - L, M, N, P
                        grassland - I, Q, S, T, U
                        bare - V, W

Forest Emphasis: water - A
                        SF 100% - B
                        SF 70-90% - C
                        SF/A 5:5-7:3 - D
                        SF/A 7:3-3:7 - E, F
                        SF <50% - G, H
                        aspen 70-90% - L, O
                        aspen 100% - M, N
                        aspen <50% - stress site - P
                        grassland - Q, S, T, U
                        bare,- V, W

Grassland Emphasis: water - A
                        forest - B, C, D, E, F, L, O
                        grassland >50% w/SF - G, H
                        grassland >50% w/aspen - P
                        mesic tundra - T
                        wet tundra - S
                        wet tundra w/willows - Q
                        dry tundra, SF krumholz <10% - U
                        sparsely vegetated - V
                        bare rock - W

Not well represented: K - prob aspen 70-100%

Not well defined: J - includes aspen, meadow, and SF/A
                        R - aircraft coverage underexposed probably
                            meadow

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SUMMITVILLE

Covertypes and Spectral Classes

Generalized: water-A
coniferous-B, C, D, G, H
mix-F
deciduous-J, M, N, O, P, Q, R
grassland-I, S, T, U, V
rocks-W

Forest Emphasis: water-A
SF 100%-B
SF 90-100%-C, D
A/SF 7:3-F
SF 50-80%-G
SF <30%-H
aspen 80-100%-J, M, N, O, R
aspen 50-80%-P
meadow w/willows; aspen 100%-Q
grassland-S, T, U, V
bare rock-W

Grassland Emphasis: water-A
forest-B, C, D, F, J, M, N, O, R
grassland 50-30% w/SF-G
grassland >70% w/SF-H
dry tundra-I, U
dry grassland 50-30% w/Aspen-P
meadow w/willows; aspen 100%-Q
wet meadow-S
moist tundra-T
dry rocky tundra-V
bare rock-W

Not well represented: E - prob SF/A
K, L - prob Aspen 80-100%
A includes some shadow

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JASPER

Covertypes and Spectral Classes

Generalized:
water - A
coniferous - B, C, D, G, H
mix-F
deciduous - J, K, L, M, N, O, P, R
grassland - I, Q, S, T, U, V
bare rock - W

Forest Emphasis:
S/F 90-100% - B
S/F 80-100% <20% A, C, D
A/SF 7:3 - F
selectively logged - SF, DF 40-70% - G, H
clear cut - slash and grass - I
aspen 80-100% - J, M, N, R
aspen 100% - K, L, O
meadow, tundra 60% w/ Aspen and Salix - P, Q
grassland - S, T, U, V
bare rock - W

Grassland Emphasis:
water - A
forest - B, C, D, F, K, L, O
selectively logged - meadow 30-60% w/SF - G, H
clear cut meadow w/slash - I
meadow 20-40% w/aspen - J
meadow <20% w/aspen - M, N, R
tundra, meadow >60% w/aspen and willow - P, Q
wet meadow (irrigated) - S
tundra w/Krumholz (<20%) - T
mesic tundra - U
rocky tundra - V
bare rock - W

Not well represented:
E - prob SF/A
A also includes shadow - SF 50-80% in
        avalanche tracks, and rocks

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GREENIE MOUNTAIN

Covertypes and Spectral Classes

Generalized:
    coniferous - B, C, D, G, H, I
    mix - E
    deciduous - F, Q, J, O, R
    grassland - P, U, V
    sparsely veg-rocky - W, A

Forest Emphasis:
    DF 90-100% - B
    DF 80-90% - C, D
    A/DF 9:1 - 6:4 - E
    Aspen 100% - F, R
    PP, DF 50-80% - G
    PP 50% - H
    PJ 40-60%, PP, DF 60% - I
    Aspen 80-100% - J, O
    grassland - P, U, V, W
    Aspen 40-70% - Q

Grassland Emphasis:
    forest - B, C, D, E, F, J, O, R
    PP <50%; grass (some sage) - H
    grass 40-60% w/ PJ+PP - I
    dry meadow - P
    grass 60-30% w/aspen - Q
    mesic meadow - U
    grass 90% w/PJ + sage - V
    sparsely vegetated - W

Not well represented
    A - prob cliffs - rocky
    K
    L
    M   > prob aspen 80-100%
    N
    S prob wet meadow
    T prob mesic meadow

WOLF CREEK PASS SW

Covertypes and Spectral Classes

Generalized:
coniferous - B, C, G, H
mix - D, E, F, J, O
deciduous - K, L, M, N
grassland - I, P, Q, R, S, U, V, T
sparsely veg-rocky - W, A

Forest Emphasis:
DWF 80-100% - B, C
DF/A 6:4-8:2 - D, E
PP/O 5:5 - F, O
PP <50% w/grass - G, H
PP <10% Oak 60-100% - J
Aspen 80-100% - K, L, M, N
grassland - I, R, S, T, U, V
meadow w/shrub - P, Q
sparsely veg-rock - W, A

Grassland Emphasis:
forest - B, C, D, E, F, J, K, L, M, N
grass, PP <50% - G, H, P
dry meadow - I, U, V
grass, forest <70% - O
meadow w/shrub - Q
mesic meadow - T
wet meadow - R, S
rocks - sparsely veg - W, A

Not well represented:
A - prob cliff-rocks
T - prob mesic meadow

WOLF CREEK PASS SE

Covertypes and Spectral Classes

Generalized:

coniferous-B, C, D, G
mix-E, F, J,O
deciduous-K, L, M, N, P
grassland-H, Q, S, T, U
bare-V, W

Forest Emphasis:

SF 80-100% (<20% aspen)-B, C, D
SF, DWF/A 7:3-3:7, some PP/oak-E, F, J, O
SF 50-70%-G
SF <20% (logged)-H
aspen 80-100%-K, L, M, N
aspen <40% - P
grassland-Q, S, T, U
bare-V, W

Grassland Emphasis:

forest-B, C, D, E, F, K, L, M, N
grassland 20% w/SF/A -J, O
grassland w/slash and SF <20%- H
grassland >60% w/aspen-P
mesic tundra and meadow-Q
irrigated pasture - S
dry tundra - T, U
bare rock-V, W

Not well represented:

I - prob dry meadow and tundra
R - prob mesic tundra

Spectral class A is topographic shadow

SUMMIT PEAK

Covertypes and Spectral Classes

Generalized: water-A
                          coniferous-B, C, D, F, G, H
                          mix-E
                          deciduous-J, K, O
                          grassland-I, Q, S, T
                          bare rock-V, W

Forest Emphasis: water-A
                          SF 90-100%-B, C
                          SF 70-90%-D
                          SF/A 4:4-E
                          SF 50-70% (may have A <30%)-F
                          SF 40-60% (no Aspen), Krumholz-G, H
                          aspen 50% w/meadow-J, O
                          aspen 80-100%-K
                          grassland-I, Q, S, T
                          bare rock-V, W

Grassland Emphasis: water-A
                          forest-B, C, D, E, K
                          meadow 30-50% w/SF,- A F
                          tundra 40-60% w/Krumholz-G, H
                          meadow 50% w/aspen-J, O
                          rocky tundra-I, V
                          wet meadow w/willow-Q
                          mesic tundra or meadow-S, T
                          bare rock-W

Not well defined: L, M, N - prob aspen 80-100%
                          P, R, U - prob mesic tundra or meadow
                          R may have sparse aspen
                          A includes shadow - bare rock

This quad was difficult due to almost half of the quad being snow-covered on the aircraft coverage, the aspen not yet leafed out, and another portion without stereo.

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PLATORO

Covertypes and Spectral Classes

Generalized:

water-A
coniferous-B, C, D, G, H
mix-E, F
deciduous-L, O
grassland-I, J, P, Q, U
bare-T, V, W

Forest Emphasis:

water-A
SF 70-100 %-B, C, D
mix and SF w/shrub (old logging)-E, F
SF 20-40%-G, H
aspen 80-100%-J, L
aspen 60-80%-O
grassland-I, P, Q, U
sparsely vegetated and bare-V, W

Grassland Emphasis:

water-A
forest-B, C, D, L, J
meadow >40% w/conifer and/or aspen-E, F, G, H
meadow <40% w/aspen-O
dry, sparsely vegetated rocky, tundra-I, T, V
wet meadow w/willow-Q
dry meadow, sometimes w/conifer <10%-P, U
bare rock-W

Not well represented:

K, M, N - prob aspen 70-100%
R, S - prob wet to mesic tundra and meadow

RED MOUNTAIN

Covertypes and Spectral Classes

Generalized:

water - A
coniferous - B, C, D, G, H
mix E, F
deciduous - J, M, O, R
grassland - I, P, Q, T, U, V
rocks W

Forest Emphasis:

water - A
SF 100% - B
SF 90-100% - C
SF/A 9:1 - D
DF/A 4:4 - E
A/DF 8:2 - 7:3 - F
SF 40-80% - G
SF 30-50% - H
stress site aspen 50-80% - J
aspen 80-100% - M, O, R
tundra, grassland - I, P, Q, T, U, V
rocks - W

Grassland Emphasis:

water - A
forest - B, C, D, E, F, M, O, R
grass 20-60% w/SF - G
grass 50-70% w/SF - H
dry meadow - I
dry meadow <50%, w/aspen - J
tundra, mesic meadow - P, Q, U
wet tundra w/willows - T
rocky dry tundra - V
rocks - W

Not well represented:

K - prob aspen 80-100%
L - prob aspen 80-100%
S - prob wet tundra
A also includes shadow - rocks, SF <60%

TERRACE RESERVOIR

Covertypes and Spectral Classes

Generalized: water-A, Y
                      coniferous-B, C, G, H, I
                      mix-D, E, F
                      deciduous-J, K, O
                      grassland-P, Q, T, U, V, W

Forest emphasis: water-A, Y
                      DF or SF 100%-B
                      DF/A 9:1-C
                      DF/A 8:2-7:1-D
                      DF/A, PP/A 6:4-5:3-E
                      A/DF, A/PP 8:2-6:2-F
                      PP 40-60%, some A-G
                      PP or DF 30-50%-H
                      PJ 20-40%, some PP + sage -I
                      aspen 80-100%-J, K, O
                      grassland-P, Q, T, U, V, W

Grassland emphasis: water-A, Y
                      forest-B, C, D, E, F, J, K, O
                      grass 40-70% w/ PP-G, H
                      sage + grass 60-80% w/ PP or PJ-I
                      wet meadow w/ willows-Q
                      wet meadow-P
                      mesic meadow-T, U
                      dry meadow, some sage -V
                      rocky dry meadow-W

Not well represented: L, M, N - prob aspen 80-100%
                       R - prob sparse aspen or mesic meadow
                       S - prob mesic meadow

For some reason Terrace and LaJara reservoirs show as the bad data
class Y. This may be due to sun glare.

CHROMO NW

Covertypes and Spectral Classes

Generalized:

water-A
coniferous-B, G, H
mix-C, D, E, F, J
deciduous-L, M, N, O
grassland-I, P, Q, R, S, U, V
bare rock-W

Forest Emphasis:

water-A
DF 90-100%-B
DF/A 8:2-C
DF/A 6:4-D
DF/A 5:5-E
O/PP; A/DF -F, J
PP 20-60% -G,H
Aspen 80-100% - L, M, N, K
O/A -O
grassland-I, P, Q, R, S, U, V
bare rock -W

Grassland Emphasis:

water-A
forest-B, C, D, E, F, K, L, M, N ———
grass w/ sparse PP <50%-G, H
dry meadow-I, U, V
mesic meadow-R
wet (irrigated) meadow-S
meadow w/shrub-P, Q
grassland w/Forest <60% - J,O
bare rock-W

Not well represented:

K - prob Aspen 100%
T - prob mesic meadow

CHROMO NE

Covertypes and Spectral Classes

Generalized:

water - A
coniferous - B, C, G, H
mix - D, E, F, J
deciduous - K, L, M, N, O
grassland - P, Q, R, S, T, U
bare - V, W

Forest Emphasis:

water - A
SF 80-100% - B
SF 70-90% - C
DWF/A 8:2-6:4 - D
A/DWF 8:2-6:4 - E
PP/O 5:3-3:5 - F, J
PP <40% w/grass - G, H
aspen 100% (includes some cottonwood) - K, L, M, N
oak 50-80% or oak/aspen 7:2-5:2 - O
grassland - P, Q, R, S, T, U
bare - V, W

Grassland EMphasis:

water - A
forest - B, C, D, E, K, L, M, N
grass >60% w/PP - G, H
grassland <30% w/PP/O - F, J
grassland <50% w/oak - O
wet meadow - P
mesic meadow w/willow - Q
mesic meadow - R, S, T
dry meadow - U
bare rock - V, W

Not well represented: I - prob dry meadow

A represents topographic shadow on steep terrain

CHAMA PEAK NW

Covertypes and Spectral Classes

Generalized: water-A
                            coniferous-B, C, G
                            mix-D, E, F, H
                            deciduous-J, K, L, M, N, O
                            grassland-I, P, Q, R, S, T, U
                            bare rock-V, W

Forest Emphasis: water-A
                            SF 100%-B
                            SF 70-90%-C
                            DWF/A 8:2-7:3-D
                            A/DWF 8:2-4:6 -5:2-E, F, O
                            DWF 40%-G
                            sparse conifer (riparian + Krumholz)-H
                            aspen 60%-J
                            aspen 60-100%-K
                            aspen 100%-L, M, N
                            grassland-P, Q, R, S, T, U
                            bare rock-V, W

Grassland Emphasis: water-A
                            forest-B, C, D, E, F, L, M, N, O
                            grass 40% w/DWF-G
                            grass (tundra) w/sparse conifer-H
                            dry meadow (tundra)-I, T, U
                            grass 40% w/aspen-J
                            grass <40% w/aspen-K
                            mesic tundra-P
                            wet meadow w/willow-Q
                            wet meadow-R, S
                            rocky, sparsely vegetated-V
                            bare rock-W

CHAMA PEAK NE

Covertypes and Spectral Classes

Generalized: water-A
                             coniferous-B, C, D
                             mix-E, F
                             deciduous-M, N, O, R
                             grassland-P, Q, S, T, U
                             bare rock-V, W

Forest Emphasis: water-A
                             SF 90-100%-B, C
                             SF 80-100%-D
                             A/SF 6:4 - 4:6-E, F
                             SF <40%-G, H
                             A/SF <30%-J
                             aspen 90-100%-M,R
                             aspen 80%-N
                             aspen 50%-O
                             grassland-P, Q, S, T, U
                             bare rock-V, W

Grassland Emphasis: water-A
                             forest-B, C, D, E, F, M, R
                             grass 60-70% w/SF or SF/A-G, H, J
                             grass 20% w/aspen-N
                             grass 50% w/aspen-O
                             mesic tundra-P, T
                             wet tundra w/willows-Q
                             wet meadow-S
                             mesic-dry meadow-U
                             sparsely vegetated - rocky-V
                             bare rock-W

Not well represented: I - prob dry meadow
                             K, L - prob aspen 80-100%
                             A and C include shadow - bare rock or sparse SF

There was no 7 1/2' base map for this quad; therefore, the definitions
are not as precise as for other quads.

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SPECTACLE LAKE

Covertypes and Spectral Classes

Generalized:

water-A
coniferous-B, C, G, H
mix - D, E, F
deciduous-J, K, M, O
grassland-I, P, Q, S, U, V

Forest Emphasis:

water-A
SF, DF 80-100%-B, C
coniferous (DWF, PP, SF)/aspen mix 7:3-3:7-D, E, F
PP 40-60% w/some aspen - G
PP <30%-H
aspen or cottonwood 70-100% - J
aspen 100% - K, M
cottonwood and willow-O
grassland-I, P, Q, S, U, V

Grassland Emphasis:

water-A
forest-B, C, D, E, F, J, K, M, O
grassland> 40% w/PP - G, H
meadow w/shrub (willow, young aspen)-P, Q
wet meadow - irrigated -S
dry meadow-U
sparsely vegetated dry meadow-V

Not well represented:

L, N - Prob aspen 80-100%
R, T - prob mesic meadow
W - prob bare rock

A also represents topographic shadow in steep areas.

LA JARA CANYON

Covertypes and Spectral Classes

Generalized: water-A,Y
coniferous-C, H, I
mix-D, E, F, G
deciduous-J, K, Ц, O
grassland-P, Q, T, U, V
bare rock-W

Forest Emphasis: water-A,Y
DWF 90%-C
DWF/A 8:2 - 7:2-D
A/DWF 5:5-6:4-E
A/DWF 8:2-F
PP/A 4:2; PP 50-70%-G
PP 20-50%; PP, DWF/A 4:1-H
PP or PJ <30%-I
Aspen 50-70%-J
Aspen (some cottonwood) 70-100%-J, K, L, O
grassland-P, Q, T, U, V
bare rock-W

Grassland Emphasis: water-A,Y
Forest-C, D, E, F, K, L, O
grassland 30-50% w/PP-G
grassland 50-80% w/PP and Aspen -H
grassland > 70% w/PP or PJ-I
grassland 30-50% w/Aspen-J
mesic meadow-P, T
wet meadow w/willow-Q
dry meadow - U
dry meadow w/sage and PP <10%-V
sparsely vegetated, dry-W

Not well represented: B-prob DWF 90-100%
M,N - prob Aspen 80-100%
R,S - prob wet to mesic meadow

Bad data class Y is often water - La Jara reservoir

VICENTE CANYON

Covertypes and Spectral Classes

Generalized:
coniferous - C, G, H, I
mix - D
deciduous
grassland - P, Q, V
bare rock - W

Forest Emphasis:
DF 70-90% - C
DWF/A 7:2 - D
PP and PJ 30-70% - G, H, I
grassland - P, Q, V
bare rock - W

Grassland Emphasis:
forest - C, D
dry grassland 30-70% w/PP, PJ and sage - G, H, I
wet meadow - P
wet meadow w/willow - Q
dry, sparsely vegetated - V
bare rock - W

This quad is dry and sparsely vegetated. Most other spectral classes
do not appear at all.

Class C also includes shadow - bare rock.

CHROMO SW

Covertypes and Spectral Classes

Generalized:
water – A
coniferous – B, C, G, H
mix – D, E, F, J, P
deciduous – K, L, M, O, R
grassland – I, Q, S, U, V
bare – W

Forest Emphasis:
water – A
DF 90–100% – B
DF 70–90% w/some aspen – C
DWF/A 8:2–2:8, PP/A and O 5:3–3:5 – D, E, F
PP 50–70% w/grass – G
PP 20–50% w/grass – H
PP/O 5:2–4:1 – 3:2–J
Aspen 80–100% – K, L, M, R
Oak 50–80% – O
O/PP 3:2–3:1 w/grass – P
PP or oak <10% w/grass or rock – I, U, V, W
grassland – Q, S

Grassland Emphasis:
water – A
forest – B, C, D, E, F, K, L, M, R
meadow 30–50% w/PP – G
meadow 50–80% w/PP – H
meadow 30–60% w/PP/O – J, P
meadow 20–50% w/oak – O
dry meadow w/ <10% PP or oak – I, U, V
sparsely vegetated w/ <10% PP – W
mesic meadow and irrigated fields – S, Q

Not well represented: N – prob Aspen 80–100%

CHROMO SE

Covertypes and Spectral Classes

Generalized:
water-A
coniferous-H
mix-D, E, F, Q
deciduous-J, K, L, M, N, O
grassland-I, S, U, V
bare-W

Forest Emphasis:
water- A
DWF/A, .PP/O 6:4-7:3-D
A/DWF 5:5-7:3-E
O/PP 5:2-2:3-F
PP <40% w/grass-H
oak 60-80%-O
oak 40-60%-J
aspen 100%-K, L, M, N
O/PP 5:3-4:2 or meadow-Q
grassland-I, P, S, U, V
bare-W

Grassland Emphasis:
water-A
forest-D, E, K, L, M, N
meadow >60% w/PP-H
meadow 100% or meadow 30-50% w/ O/PP - F, Q
meadow 20-40% w/oak-O
meadow 40-60% w/oak-J
irrigated pasture-S
dry meadow-I, P, U, V
bare rock-W

Not well represented:
B, C, - prob DWF 60-90%
G - prob PP 50-80% w/grass
R, T - prob mesic meadow

CHAMA PEAK SW

Covertypes and Spectral Classes

Generalized:

water-A
coniferous-B, C, D, G
mix-E, F, H
deciduous-J, K, L, M, N, O, R
grassland-P, Q, S, T, U
bare rock-V, W

Forest Emphasis:

water-A
DF, · SF 100%-B
DF, SF 70-90%-C
SF, DF 60-80%, <20% aspen - D, G
A/DF 6:4-8:2-E, F
cottonwood, Blue spruce w/gravel-H
oak, aspen, - cottonwood 70%-J.
aspen 100%-K, L, M, N
aspen 50%; oak/aspen 4:3-5:5-O
aspen 60-80%-R
grassland-P, Q, S, T, U
bare rock-V, W

Grassland Emphasis:

water-A
forest-B, C, D, E, F, K, L, M, N
grassland 30-40% w/DF-G
grass and gravel bars w/cottonwood-H
grassland 30%-50% w/oak, aspen-J, O, R
mesic meadow-P
wet meadow w/willows-Q
irrigated pasture-S
dry tundra-T, U
bare-sparsely vegetated-V
bare rock-W

Not well represented:

I - prob dry tundra
A is also shadow - bare rock and sparse SF

CHAMA PEAK SE

Covertypes and Spectral Classes

Generalized: water – A
                     coniferous – B, C, G
                     mix – E, D, F, O
                     deciduous – K, L, M, N
                     grassland – J, P, Q, R, S, T, U
                     Bare – V, W

Forest Emphasis: water – A
                     SF 100% – B
                     SF 90% – C
                     SF/A 4:1-7:3 – D, E
                     A/SF, DWF 5:5-6:3 – F
                     SF 50-80% – G
                     aspen, SF <60%, or meadow 100% – J, N, O
                     aspen 80-100% – K, L, M
                     grassland – P, Q, R, S, T, U
                     bare – V, W

Grassland Emphasis: water – A
                     forest – B, C, D, E, F, K, L, M
                     grass – <30% w/SF – G
                     meadow 100% or grassland >40% w/aspen or SF –
                         J, N, O
                     wet meadow – P
                     wet meadow w/willow – Q
                     mesic meadow – R, S
                     dry meadow – T, U
                     bare and sparsely vegetated – V, W

Not well represented: I – prob dry meadow

A also represents topographic shadow in steep areas

CUMBRES

Covertypes and Spectral Classes

Generalized:
water – A
coniferous – B, C, D
mix – E, F
deciduous – K, L, M, N, O, R
grassland – G, H, I, J, P, Q, T, U
bare – V, W

Forest Emphasis:
water – A
SF 80–100% – B, C
SF 50–80% (selectively logged) – D
selectively logged (SF 40–80%) or
    SF/A 7:3–3:7 – E, F
aspen 80–100% – K, L, M, N, O, R
aspen <50% – J, S
grassland – G, H, I, P, Q, T, U
bare – V, W

Grassland Emphasis:
water – A
forest – B, C, K, L, M, N, O, R
meadow 20–50% w/SF (selectively logged) – D
meadow 20–60% w/SF or mix 100% – E, F
meadow >50% w/aspen – J, S
mesic meadow (some clear cut) – G, H, P, T, U
dry meadow – I
wet meadow w/willow – Q
sparsely vegetated – V
bare rock – W

A also represents topographic shadow in steep areas.

OSIER   Covertypes and Spectral Classes

Generalized:

coniferous-G, H
mix-B, C, D, E, F
deciduous-J, L, M, O
grassland-I, P, Q, U
bare-V, W

Forest Emphasis:

DWF/A (some pure PP or DWF) 8:1-3:3-B, C, D
A/DWF 8:2-5:4-E, F
coniferous mix DWF/PP, DWF/SF 50-80%-G, H
aspen 50-90%-J, O
aspen 80-100%-L, M
grassland-I, P, Q, U
bare-V, W

Grassland Emphasis:

forested-B, C, D, E, F, L, M
meadow 20-50% w/conifer-G, H
meadow 10-50% w/aspen-J, O
dry meadow-I
mesic meadow-P, U
wet meadow w/willow-Q
sparsely vegetated-V, W

Not well represented:

K, N - prob aspen 70-100%
R, S, T - prob mesic meadow, maybe some
               aspen in R
A - prob topographic shadow

FOX CREEK

Covertypes and Spectral Classes

Generalized: coniferous - C, G, H
                       mix - D, E, F
                       deciduous - J, K, L, M, N, O
                       grassland - I, P, Q, S, T, U
                       sparsely vegetated - V, W

Forest Emphasis: DWF and/or PP 70-90% - C.
                       DWF, PP/A 8:2-2:8 - D, E, F
                       DWF and/or PP 50-70% - G
                       PJ 30-60% - H
                       PJ or PP <20% w/grass I
                       aspen or cottonwood 60-80% - J, L, O
                       aspen 80-100% - K, M
                       grassland - P, Q, S, T, U
                       sparsely vegetated (includes sage) - V, W

Grassland Emphasis: forest - C, D, E, F, K, M
                       grassland 30-50% w/DWF or PP - G
                       grassland 40-70% w/PJ - H
                       grassland >80% w/PJ or PP - I
                       grassland 20-40% w/aspen and cottonwood
                           - J, L, O
                       wet meadow w/willow - Q
                       wet meadow - P, T
                       mesic meadow - agricultural S, U
                       sparsely vegetated (includes sage) - V, W

Not well represented: A - prob topographic shadow
                       B - prob DWF >70%
                       N - prob aspen 80-100%
                       R - prob mesic meadow

BRAZOS PEAK NW

Covertypes and Spectral Classes

Generalized:
water-A
conifer-B, C, D, G, H
mix-E, F, J, O
deciduous-K, L, M, N
grass-P, Q, R, S, T, U, V, I
rocks-W

Forest Emphasis:
water-A
S/F 90-100%-B
SF, DWF 80-90%-C
SF, DWF 70-80% - D
aspen/SF or DWF - E, O
sparse conifer/aspen - F
PP/grass <40% - G, H
aspen <60% - J
aspen 100% - K, L, M, N
old logged - P
grassland - Q, R, S, T, U, V, I
bare rock - W

:assland Emphasis:
water - A
forest - B, C, D, E, F, J, K, L, M, N, O
grass <60% /PP <40% - G, H
grass and shrub - I
old logged, sparse conifer - P
willows & wet meadow; oak - Q
edge of aspen & meadow - R, S
wet meadow (some irrigated) - T
mesic meadow - U
dry rocky meadow - V
bare rock - W

There was no 7 1/2' base map for this quad; therefore, the definitions
are not as precise as for other quads.

BRAZOS PEAK NE

Covertypes and Spectral Classes

Generalized:
water-A
conifer-B, C, D, G, H
mix-E, F
deciduous - J, K, L, M, N, O
shrub/meadow-I, P, Q
grass-R, S, T, U, V
rocks-W

Forest Emphasis:
water-A
S/F 90-100%-B
S/F 80-90%-C
DWF 70-100%-D
conifer/aspen-E
aspen/conifer-F
conifer <40% w/grass-G, H
shrub (sage)-I
aspen <70%-J
aspen 100%-K, L, M, N, O
shrub/meadow-P
willow/meadow-Q
grass-R, S, T, U, V
rocks-W

Grassland Emphasis:
water-A
trees-B, C, D, E, I, J, K, L, M, N, O
grass >60% /conifer <40%-G, H
grass/shrub (<30%)-I, P
willow/wet meadow-Q
wet meadow-R, S
mesic meadow-T
dry meadow-U
rocky meadow-V
rocks-W

There was no 7 1/2' base map for this quad; therefore, the definitions are not as precise as for other quadrangles.

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BIGHORN PEAK

Covertypes and Spectral Classes

Generalized:
no water
conifer-B, C
mix-E, F, G, H
shrub-I,Q
deciduous-J, K, L, M, N, O
grass-P, R, S, T, U, V
rocks-W

Forest Emphasis:
no water
DWF 90-100% - A, B, C
PP/oak; DWF/aspen-D, E
oak/PP-F
Piñon/juniper/oak 80%-G, H
sage; rabbit brush-I
aspen; oak 60-70%-J, O
aspen 80-100% - K, L
aspen 100%-M, N
grass-P, R, S, T, U, V
willow/meadow-Q
rocks-W

Grassland Emphasis:
no water
trees-A, B, C, D, E, F, G, H, K, L, M, N
shrubs-I
oak; aspen/grass (40%)-O, J
conifer/grass (60%)-P
willow/wet meadow-Q
wet meadow-R
mesic meadow-S, T
dry meadow-U
rocky dry meadow-V
bare rock-W

APPENDIX B

CLASSIFICATION EVALUATION
FOR COMMUNITY AND GENERALIZED
VEGETATION LEVELS

Final evaluation figures for classification. These figures are for the homogenous photointerpretation test fields using the moderate interpretation of the community types. The number to the left of the slash is the accuracy figure for that covertype; the number to the right of the slash is the percentage of the test sample represented by test fields of that covertype.

Community Level

Community Type	Bighorn Peak	Chama Peak SE	Chromo NE	Platoro	Spectacle Lake	Wolf Creek Pass NE
dense conifer	94.1/ 1.8	98.5/ 23.6	83.8/ 10.3	91.0/ 40.3	83.5/ 4.8	68.1/ 25.6
sparse conifer	64.4/ 9.3			61.2/ 3.6	59.7/ 3.1	
coniferous/deciduous	88.3/ 35.4	100/ 1.2	97.1/ 30.4	95.8/ 5.2	91.3/ 33.3	93.7/ 33.3
deciduous/coniferous	49.5/ 10.6	80.8/ 2.3	87.0/ 8.5		76.6/ 15.2	95.7/ 5.1
aspen	54.8/ 9.9	85.4/ 14.5	83.8/ 7.3	94.1/ 2.5	43.9/ 8.3	95.1/ 3.0
oak			51.4/ 13.7			
wet and mesic grassland		93.6/ 9.6	61.5/ 17.8	72.6/ 17.0	88.2/ 16.2	47.2/ 10.4
grassland	88.4/ 7.3	80.7/ 36.9	67.5/ 9.6	63.2/ 7.0	80.0/ 15.7	69.2/ 10.4
sparsely vegetated	89.7/ 22.7	97.1/ 3.0		68.0/ 11.3	48.1/ 2.4	38.7/ 6.8
bare rock	61.5/ 2.8	67.0/ 8.8		81.9/ 6.1		38.0/ 3.6
water			71.0/ 2.4	100.0/ 6.9		
All covertypes combined	78.2	86.3	77.8	82.7	80.3	73.8

79.8% – merged accuracy for six intensive quadrangles at the community level

Final evaluation figures for classification. These figures are for the homogenous photointer-pretation test fields using the moderate interpretation of the generalized level. The number to the left of the slash is the accuracy figure for that covertype; the number to the right of the slash is the percentage of the test sample represented by test fields of that covertype.

Generalized Level

Covertype	Bighorn Peak	Chama Peak SE	Chromo NE	Platoro	Spectacle Lake	Wolf Creek Pass N.
Coniferous	69.9/ 11.0	98.9/ 23.6	83.8/ 10.3	93.5/ 43.9	89.5/ 8.1	72.4/ 26.1
Deciduous	54.8/ 9.9	85.4/ 14.5	75.9/ 21.0	94.1/ 2.5	43.9/ 8.3	95.1/ 3.0
Mix	94.3/ 46.3	100.0/ 3.5	98.6/ 38.9	97.2/ 5.2	93.7/ 48.9	97.1/ 38.9
Grassland	88.4/ 7.3	86.6/ 46.6	63.6/ 27.3	78.2/ 26.0	84.7/ 32.2	61.8/ 21.2
Sparsely vege-tated and bare	87.5/ 25.4	80.6/ 11.8		73.7/ 17.4	48.1/ 2.4	49.7/ 10.6
Water			71.0/ 2.4	100.0/ 6.9		
Overall	85.4	89.1	82.1	87.0	85.2	77.9

84.4% — merged accuracy for six intensive quadrangles at the generalized level

APPENDIX C

U.S. FOREST SERVICE RESPONSE
TO FINAL PRODUCTS OF THIS PROJECT

8200

May 5, 1976

Ms. Paula Krebs
Institute of Arctic and
Alpine Research
University of Colorado
Boulder, Colorado 80302

Dear Paula:

I had a tough time locating any birch bark so this letter must suffice. I must also apologize for the disjointed approach but its the only way I know to answer all your questions.

From the tone of your letter I felt you were overwhelmed by the terms, scope and intensity of the possible project applications for the data. My purpose then will be to give a better explanation of the various use levels and some explanation of the forestry lingo.

Stage I and II are two distinct levels of inventory with separate objectives as follows:

Stage I survey or inventory is a basic inventory which furnishes the management planner area and volume information, condition classes, site and yield class indexes, and the general distribution by age classes within the Working Circle. This information is for the Working Circle as a whole. From this information the management planner can make an overall evaluation of the condition and needs of the Working Circle and develop management objectives. The Stage I inventory is an extensive inventory designed to furnish how much and what, but generally does not tell where stands, sites, etc., are located.

Compartment examination, or "Stage II" inventory, provides information as to the condition of specific stands, where they are located, and what action is needed to bring each stand into acceptable condition. Stage II is different from Stage I in that it localizes the sample area by giving the stand or area an identification number. This number, coupled with the subcompartment and compartment number, gives the sample area an on-the-ground designation. The stand or area with its corresponding number and boundaries can then be transcribed from the photos to maps and/or to computer programs to become part of the permanent compartment records.

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The Stage II inventory procedures are designed to be compatible with, and supplemental to, Stage I inventories. Computer programs and sub-routines used to compute Stage II data are modified versions of those used for Stage I inventories. In essence, the two inventory procedures are additive, permitting periodic updating of inventory statistics.

One term in the above explanation that may give you some trouble is "Working Circle". This is an area of land with similar overstory types. For the Rio Grande it would be the entire San Juan range.

The vegetative types shown on the "forest emphasis" and combined with slope aspect is more accurate than Stage I inventory. Estimated accuracy of Stage I is about 60%. Cost would be about 50¢ per acre over the entire quadrangle. With a crew of four, it took almost three years to go from the photo interpretation phase to the Automatic data processing (ADP) stage on about 800,000 acres.

Paula, this is a back door approach to answer your questions but its the best I have.

Stage II inventory costs $1.20 per acre to develop the information thru the ADP stage. I had a crew of four people for three months that completed 6700 acres of Stage II. This is just timbered land.

By combining slope-aspect with vegetative type I feel we can do the job with similar accuracy (approximately 80%) in about 1/2 the time because we could operate from the computer map to locate our stands. That would eliminate much photo interpretation and transfer of data from one photo to a map, then changing map scales and transfer data from one map to another. Second, it would much more accurately locate those stands under 40% slope which is our rule-of-thumb breaking point for logging operations with conventional equipment (rubber tired skidders, etc.) or unconventional or high lead or sky-line operations. Last, it would give the forester information on stand homogenity type, etc. so that he could make a determination on the number of points to put into a stand. This could, if used properly and with some judgement significantly reduce field time while maintaining comparable accuracy.

I hope the above gives you sufficient information with which to make the cost analysis. If not, please let me know what other information is needed.

I would like to express my enthusiasm concerning the use of this tool at the project level. By project I mean the development of transporta-tion cooridors, timber sales, special studies. as Wild and Scenic River Study and planning as Transportation System Planning.

For information I'd like to walk you through one idea I have to marry the data set with planning and project application.
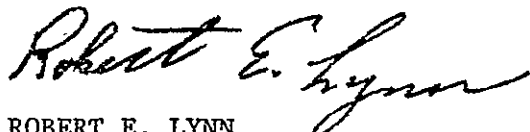
·The setting for this is the area between the Alamosa and Conejos Rivers. This country is lightly roaded but contains a vast bank of resources. The first step in the process is to determine what those resources are, where they are located and how much is there. For sake of simplicity I will talk only to timber. To do this job now would require one to transfer the timber types from a 2" map to the 15 min. quadrangle. Next, he would have to locate, very subjectively, the slope aspect over this. The last step would be to combine slope aspect and overstory type to develop a map showing the location of timber resources on slopes greater than 40% and less than 40%. I will guess the accuracy of this product at 40%. Our next step would be to do a transportation cooridor analysis showing all possible alternative routes into the area.

Once the cooridor analysis is completed the alternate routes need to be overlayed on the topographic map. Then an evaluation of the timber resources that can be served by each alternative route is made. Of course the time required to do this is proportionate to the size and complexity of the area being analyzed. Upon completion of this phase we are ready to make a decision on the alternative route. However, the job has just begun for the forester who has the responsibility for preparation of the sale. Please realize the above job must be completed three years prior to the selling of the sale(s).

The combination of the forest emphasis map with slope-aspect allows the forester to do a better quality job in shorter time, for completion of Stage II inventory as previously discussed and in knowing more specifically the areas to be flagged and marked and in knowing what road system is needed to serve the block. I feel very strongly that using this method will reduce the total number of roads, allow us to build the needed roads to the proper standards so that they can handle industrial as well as recreation traffic safely and adequately for some time to come. Finally, I think it can also be shown that the impacts and effects on the soil and water resources will be reduced in the long run.

Well so much for my sermon Paula. I just hope this provides you with enough indepth information for you to complete the analysis I feel needs to be made.

Sincerely,

ROBERT E. LYNN
District Ranger

Addendum to letter
Paula Krebs, May 5, 1976

I would like to take a few minutes to look in retrospect at the progress
we have made toward the application of LANDSAT MSS data to the forestry
field.

As we began the interaction between yourself and your staff and the
Forest Service personnel, we went through a perplexing period where
both parties were struggling with the concept. First, to fink out what
LANDSAT could do and second how it could have application in the
forestry field. In the first several months of the project many ideas
surfaced. Some of the ideas were handled very quickly with outstanding
results. To mention a few of these is the completion of the mass
stability mapping for the Chama River, the development of the
methology and final product of a landtype association soil inventory
of the planning unit. Another benefit from the effort is the continuous
education of the Forest Service personnel about LANDSAT.

Of course, many of the ideas were for more advanced utilization of
LANDSAT data which until lately we were not able to handle. However, I
feel significant advances have been made in the practical application of
this data to Forestry. Within the last month we have finally arrived
at a point where some of the ideas can be tested, I wish we had
additional time to carry more of the ideas through with sufficient
time to critique our efforts in terms of increased quality, accuracy
and cost effectiveness. I hope that you will take the time to portray
our efforts and accomplishments to the Goddard staff.

8200
May 14, 1976

Paula V. Krebs
University of Colorado
Institute of Arctic and
Alpine Research
Boulder, Colorado 80302

Dear Paula:

We feel that LANDSTAT data can be used in land use planning, in
various types of short range and long range functional and project
planning and, in time, will be useful in helping to determine
accomplishment in the various functional areas and projects.
These functional areas and projects include wildlife habitat,
timber management, domestic livestock range, watershed management,
avalanche area determination, transportation system location
and others.

The data, as requested, will be used in the Southern San Juan
Mountains Unit land use planning effort, Stage I timber inventory,
Stage II timber inventory, developing timber sales programs and
in determining and mapping key big game habitat areas.

The data were requested in the combinations that are shown in your
letter of April 28, 1976 because;

1. Timber sales programs development

    a. Slopes less than 30% are usually tractor logged.

    b. Slopes over 30% are normally logged by some other means.

2. Road layout

    a. 0-15% - almost no restrictions except where soft areas
    require gravel.

    b. 15-30% - generally can be roaded but must watch for
    potential erosion.

    c. 30-45% - same but usually cable logged.

    · d. 45%+ - difficult road building, costs normally high and
    mass movement potential increases.

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3. Aspect

   Generally not too important in high rainfall (high elevation) areas but it is most important below 8,000 feet. It is also useful in game range determination and management.

4. Vegetation type determination

   The need for species (vegetation type) identification should be evident from our previous discussions.

5. Density
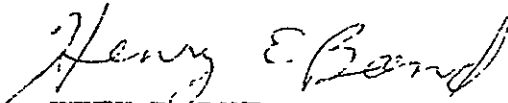
   Has many management implications such as; it indicates volume/acre, if we can develop density/volume factors on the Forest; and it indicates the understocked stands that need reforestation.

6. Savings

   We have not estimated the savings in dollars and manpower that might evolve through the use of the LANDSAT data. However, the data as requested will provide a point in time source of data that can be used in present and future plans and programs. The data requested is now available from several different sources-- the 1956 vegetation type maps, 1956 aerial photos, 1973 aerial photos, USGS contour maps, etc. However, it requires time to interpret, adjust and combine data obtained from these sources. Therefore, it is hopeful that data can be combined with a savings in time and dollars through the use of the LANDSTAT facilities.

Thank you for your cooperation and input into this effort. It is hopeful that the results will be of benefit to both of our organizations.

Sincerely,

HENRY E. BOND
Project Coordinator

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2600
May 18, 1976

Dr. Paula Krebs
University of Colorado
Institute of Arctic and Alpine Research
Boulder, Colorado 80302

Dear Paula:

I received the big game winter range data and the hand carried
letter brought by Page Spencer. We will be starting the Pagosa
Planning Unit this summer, with the major emphasis after July 1.
We are digitizing some soils data, but on a very small area and
not in the Pagosa Planning Unit. At this stage of that program,
the digitizing is more time consuming than using an overlay. Per-
haps this situation can be improved, but it does not look too
promising right now.

Your thoughts concerning the various combinations of vegetation
with topographic features are exactly the kind of opportunities
where we can make the most use of the products you offer. It is
now our (Forest Service) responsibility to determine the most
logical combinations that will mean something to us for land use
planning purposes and project purposes. With the number of com-
binations that exist and the rapid flexibility of making different
combinations, we should be able to come up with those that are most
significant. Assuming that we will continue to use soils informa-
tion on an overlay basis, we could then construct a map using a
good combination of vegetation-topographic features with a soils
overlay and really pinpoint the good, medium, and/or poor sites
for project proposals.

In response to your request for permission to reproduce my com-
ments about the big game winter range output, feel free to use
anything which you believe will be helpful.

After looking at the thematic map, I believe we should have had
many different parameters than those listed. For slope percent
we need 10 to 80 percent, broken down in 20 percent categories.
On aspect, we should have 135° to 315°. On elevation, we need
from 6000' to 9000'. And on vegetative types, we should have
ponderosa pine-oakbrush, oakbrush-mixed browse, and all grass-
land types. By using this set of parameters, we can identify

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6200-11 (1/69)

2

the areas that produce forage for big game animals and the areas
that are most snow-free because of aspect, slope and elevation.
To identify this set of parameters using the conventional methods
would require at least four overlays and the manual combination
of these. The tabular data is useful in that when combined with
the map, it indicates where certain types are located, the acreage
of same, and then the percentage of the total area that is actually
producing forage. The Forest Service presently has a generalized
map of the big game winter range. With this kind of overlay, we
can pinpoint the areas of actual use and ascertain the percent of
the total area that is used. This kind of information will be
extremely helpful when considering the impacts of certain project
proposals such as timber sales, intensive range management prac-
tices, ski area development, etc.

In regards to my role in the planning process, I am responsible
for the collection of technical input into the inventory of the
plant and animal portions of ecosystem delineation and descrip-
tion. Professional judgement is needed regarding where various
plant zones are found, how they are used by domestic and wild
animals, etc. In connection with this aspect, I offer recommen-
dations from my specialty standpoints on the various alternatives
for land use allocation of certain areas of land. My position on
the Forest is as a Wildlife Biologist and Range Conservationist
working out of the Supervisor's Office. My principal duties are
to assist the District Rangers with technical input regarding
project proposals and on-going projects. In the past two or
three years, land use planning has received high priority, and
I have been directed to furnish input into these efforts.

Sincerely,

DAVID W. COOK
Wildlife Biologist

APPENDIX D

DESCRIPTION OF SOFTWARE FOR COMBINING
CLASSIFICATION AND TOPOGRAPHIC DATA
(USER'S GUIDE AND PROGRAM DOCUMENTATION)

The software for forming combinations of spectral classes and topographic groups was generated as part of this study and the description included here is intended as a users guide and program documentation. Three elements are of importance here: A) The format of the input MIST tapes, B) the LARSYS results output tape format, and C) the combination program. These are discussed in the order A, B, and C.

A. Grouped Merged MIST Tape Format.

The grouped and merged tape contains the classification and topographic data in coded form in four channels of a LARS MIST (Multispectral Image Storage Tape) format. The codes are integers defining spectral classes and topographic data ranges. The meaning of the code number is determined by the merge process and for the tape generated for this study the code meanings are listed in the text in Section D.6. Channel 1 contains the spectral classes, Channel 2 the elevation groups, Channel 3 the slope groups and Channel 4 the aspect groups.

The format of the MIST tape is fixed for all LARS data tapes and is widely used. This format is described in detail in LARSYS System Documents, but is briefly explained here. The MIST tape format consists of three types of tape records: 1) ID (Identification) Record, 2) Data Records and 3) End of File Records. A file of merged data starts with an ID record and is ended by an end of file record with any number of data records between the two.

1. ID Record – The standard ID record contains many items of information regarding the multispectral scanner data it normally holds. For the present application this ID record is being used to store coded data and most of the storage locations are not used. The record must contain 200 data full words (800 bytes) and the following full words of the record are used, all others are zero.

		Fortran Format
ID(1)	Tape Number	I
ID(2)	File Number	I
ID(3)	Run Number	I
ID(4)	Zero	I

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ID(5)   Number of Channels (4)   I

ID(6)   Number of Samples/Channel   I

ID(20)   Number of Lines   I

2. Data Records – Each data record represents one line of imagery from the original data set classified. Each pixel or sample is represented by a 8 bit word called 8 byte which has an integer value range of 0 to 255. In this application only the first few integers are used. All the samples from one channel follow in sequence. At the end of each sequence of samples for a channel are six calibration bytes which are not used here (zeros). The samples for the second channel follow, then the third, etc. The beginning of each record contains four bytes, the first two of which contain the line number in half word (2 byte) format and the second two are not used. The following diagram describes the byte arrangement.

ID (6) Bytes

1 Byte	1 Byte									1 Byte
Sample 1	Sample 2	• • •	Sample ID (6) -6	CO	VCO	C1	VC1	C2	VC2

2 Bytes	2 Bytes					
Line Number 2	Roll Para- meter	Data from Channel 1 for Line 2	Data from Channel 2 for Line 2		• • •	Data from Channel ID(5) for Line 2

ID(5)   *ID(6)+4 bytes

800 Bytes					
ID Record	I R G	Data Record for Line 1	I R G	Data Record for Line 2	Data Record for Line ID(20)
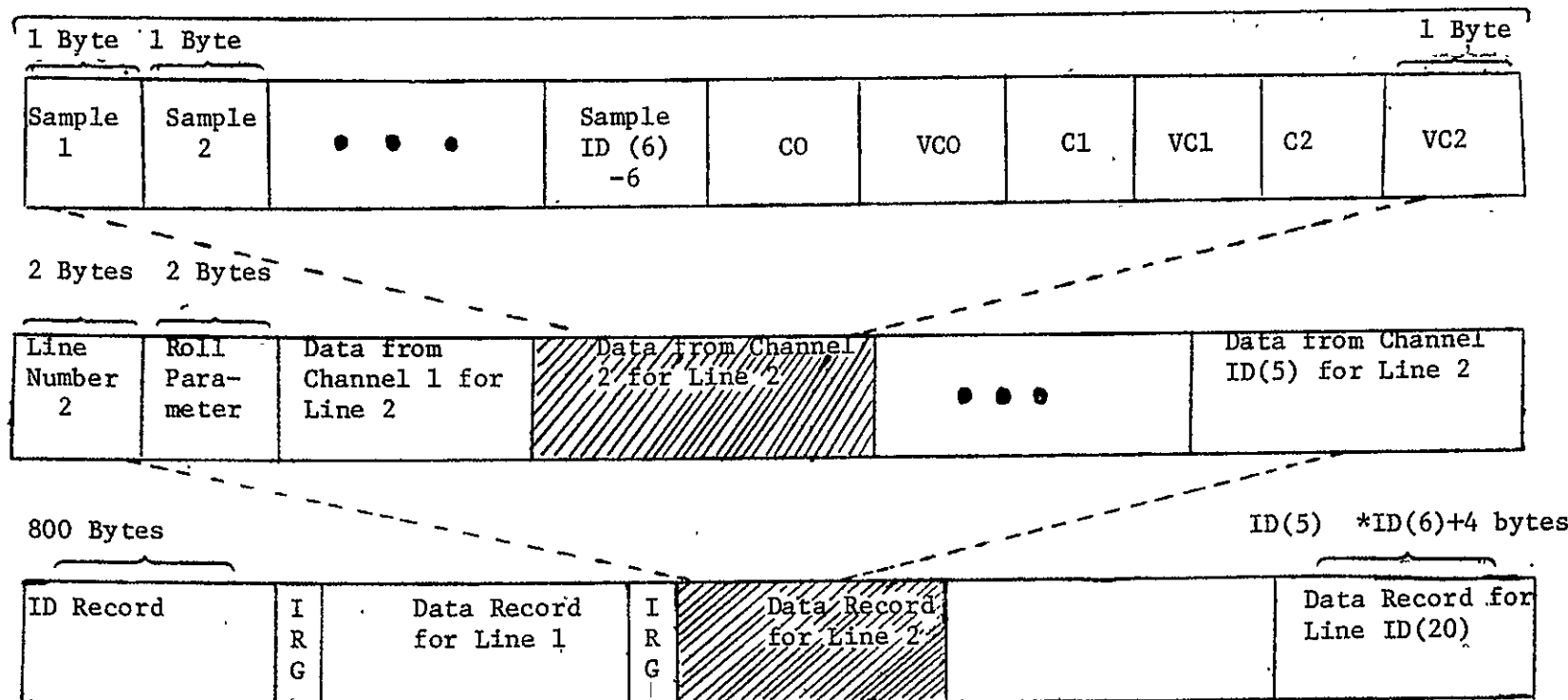
Diagram of MIST Tape Format

3. End of File Records – These are tape unit generated one byte ranks signalling the end of a file. One such mark follows the last data record.

B. Results Tape Format.

The LARS results tape is normally written by the classification algorithm and it contains the classification decision for each pixel, a confidence index for each decision and the training fields and statistics used for the classification. In the application here the format is used only to gain access to the LARSYS display programs for symbol printout maps, tabulations, and color image displays. Thus, the statistics storage, and confidence index data is not present other than the value zero to fill the space.

The documentation from the LARSYS System Manual is included next to give a full description of the results tape format. The portions used are then discussed.

Classification Results File

The Classification Results File is produced by the CLASSIFYPOINTS function and is the primary input to the PRINTRESULTS, COPYRESULTS, LISTRESULTS, and PUNCHSTATISTICS functions. The file may be output on either tape or on disk, however, the latter two functions will accept it for input only if it is on tape.

When the file is produced on tape, special support is provided to allow more than one results file to be placed on a single tape reel. The last file on the tape is followed by a special "marker" file, which contains only a single type 1 record (see the record types below). A special file type code is then used to indicate that this is the last file on the tape and that it is not a true data file.

The first two parts of this description describe the file usage and the format of the file under normal conditions. The last part describes the temporary records that are created when the SUSPEND command is issued. These temporary records are always destroyed when processing of the "suspended" file is restarted.

File Usage:

The Classification Results File is created by the CLASSIFYPOINTS

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function. Copies of the file can be created with the COPYRESULTS function. On the following page is a list of program modules that create records on the results file. These are all modules in CLASSIFYPOINTS. All records of COPYRESULTS output file are created by the module copy.

Record Type	Module Writing
1	MMTAPE writes this record if the file is on tape and is being initialized. Otherwise, CLAINT writes it. The form of this record with filetype = 1 is written by CLSFY2 (or by CLSFY1 in the case of an error termination).
2	CLAINT
3	CLAINT
4	CLSFY1
5	CLSFY2
6	CONTEX
7	CONTEX
8	CLSFY2

The LISTRESULTS, PUNCHSTATISTICS, COPYRESULTS, and PRINTRESULTS functions all read the results file on tape. Only COPYRESULTS and PRINTRESULTS can read the results file on disk. All the results functions leave the results tape positioned at the beginning of the next file after the one they processed. The results file on disk is left positioned at the end.

All functions that read the results file use MMTAPE to mount and position it if the file is on tape. MMTAPE reads the first record of the file and then repositions it back at the beginning of the file.

For LISTRESULTS, PUNCHSTATISTICS and COPYRESULTS, all records are read by the module COPY, and RESCOP initially reads the first two records.

In PRINTRESULTS, record types 1 and 2 are read by PRINT. Record type 3's are read via a CALL to RDTRN. Record type 4 is read by STATS and by DISPY1. DISPY1 may also read over record types 6 and 7 in order to get to the next record type 5. Record types 6 and 7 are read by DISPLY. Record type 8 is read by DISPY1.

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File Format:

The Classification Results File contains eight different types of
records. The format, size, and content of each entry in each of these
records, and the number of records of each type that occur in a single
file, is described below. All records are written using Fortran
unformatted I/O, a variable spanned (RECFM = VS) record form and a
block size of 1500. This record format is described in detail in IBM
reference manual GC28-6817-3, Fortran IV (G and H) Programming Guide,
pp 69-70 ("Unformatted Control"). The records are unblocked. Briefly,
if the logical record is 1492 bytes or less, the physical record con-
sists of 8 bytes of control information plus the logical record. If
the logical record is 1493 bytes or more, it is spanned onto additional
physical records each beginning with 8 bytes of control information.
The final physical record written may be less than 1,5000 bytes.

Each record begins with a two word prefix which precedes the data
described below. The first word contains the record type as a
fullword integer. The second word is set to zero for record types
1-4 and record type 8. For record types 5-7, it contains the area
number as a fullword integer. The first area classified in the file
is area 1, the second area classified is 2 and so forth. The record
sizes shown below do not reflect this additional 8 byte prefix, which
should be added to determine record size.

Record Type 1. This record contains identification information for
the file. Each results file has one record of type 1 and is always
12 fullwords (48 bytes) long.

Format	Size	Description
I*4	1 fullword	Tape Number (zero if file is on disk) A scratch tape is number 0
I*4	1 fullword	File Number (zero if file is on disk)
I*4	1 fullword	LARSYS Version Number (currently the value is 3)
I*4	1 fullword	Filetype (0 for a results file, 1 for a restart file, and -1 for a file containing only record type 1)
I*4	1 fullword	Serial Number in the form "ydddsssss" where y = the last digit of the year, ddd = the day of the year, and sssss = number of seconds since midnight

Format	Size	Description
I*4	1 fullword	Level flag (0 for LARSYS Version 3,1 for modified classification results file)
I*4	6 fullwords	Not currently defined though may be in the future. All six words are now zeroes.

Record Type 2. Each file has one variable length record of type 2. It contains a number of entries relating to the channels, classes and pools that were used in the classification and varies in size with the number of each of these that were used.

Format	Size	Description
I*4	1 fullword	Number of classes used in calcu-lating statistics before grouping into pools.
I*4	1 fullword	Number of channels used in the classification.
I*4	1 fullword	Number of training fields used in the classification.
I*4	1 fullword	Number of classification pools

The size of the next segment varies with the number of channels (represented by a ch in the size column).

I*2	(1 x ch) halfwords	A vector of the channel numbers for all channels used in the classification. Channel numbers are in ascending sequence, and each is stored as a halfword integer.
I*2	(1 x ch) halfwords	A vector containing the calibration codes for the channels used in the classification. (See LARS Infor-mation Note 071069). Same format as above.
R*4	(1 x ch) fullwords	A vector containing the upper wave-length band limits of all channels (in micrometers) used in the classi-fication.
R*4	(1 x ch) fullwords	A vector containing the lower wave-length band limits of all channels (in micrometers) used in the classi-fication.

Alpha	(8 x po) .bytes	A list of the eight byte names for all of the pools, in ascending order by pool number.
I*2	(2 x po) halfwords	Pool Pointer Matrix (POLPTR) A 2 by j matrix where j = the number of pools. POLPTR (1, j) = the number of classes in pool j, and POLPTR (2,j) = the location of the first class for pool j in the Pool Stack Vector (POLSTK) below.
I*2	(1 x cl) halfwords	Pool Stack Vector (POLSTK). This is a vector containing the class number of all classes used in the statistics deck grouped by classification pool.
R*4	(1* po) fullwords	Weight vector (PROB). This vector contains the weights assigned to each pool in the classification.
Alpha	20 bytes	The date the classification was performed in EBCDIC. For example Sept. 11, 1972 would be represented as "Sept,11b1972bbbbbbbb".

Record Type 3. These records provide a copy of the Statistics File that was used in the classification run. There is one logical (and physical) record of type 3 created for each "card" in the Statistics File. The record consists of the exact 80-column stage of the card. See the description of the Statistics File in this section for more details on its organization and content.

Record Type 4. This record contains the covariance matrices and the mean vectors for the reflectance values of the channels for each of the classification pools. The record is of variable length, varying with the number of pools and number of channels used in the classification. (Represented by po and ch in the size column).

The covariance matrices for all of the pools are written first:

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Format	Size	Description
R*4	$\dfrac{(ch^2+ch)po}{2}$ fullwords	The Covariance Matrix for each classification pool is placed in the record ascending pool number sequence. Only the lower triangular "half" of the symmetrical matrix is stored and the individual elements (values) are stored as floating point numbers in "column by row" sequence. Hence each element C_{ij} of each matrix is stored according to the sequence; C_{11}, C_{21}, C_{22}, C_{31}, C_{32}, C_{33}, C_{41}, etc.

The mean vectors of all of the pools follow the covariance matrices:

Format	Size	Description
R*4	(1 x ch) po fullwords	The Mean Vector for each classification pool is then placed in the record in ascending pool number sequence. Each individual vector has the mean value for each channel used in the classification ordered in ascending channel number sequence.

Record Type 5. This is the area identification record. There is one such record at the beginning of the results records for each area considered in the classification run. It is followed by the series of results records (record type 6) which contain the classification results of each line in the area; and by a single "end-of-the-area" record (record type 7) following the last results record. Record Type 5 is fixed length and is always 309 fullwords long.

Format	Size	Description
I*4	1 fullword	The number of points classified in each line of record type 6.
I*4	1 fullword	The number of lines classified in the area
I*4	17 fullwords	The INFO array used in CLASSIFYPOINTS in (CLACOM)

INFO(1) = run number
INFO(2) = field designation (first four characters)
INFO(3) = field designation (last four characters)
INFO(4) = line number of first line of field
INFO(5) = line number of last line of field

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Format	Size	Description

INFO(6) = line interval
INFO(7) = column number of first
          column·
INFO(8) = column number of last column
INFO(9) = column interval
INFO(10-11) = class name-eight
              characters
INFO(12-17) = user information that was
              contained in card columns
              59-80 of the Field Descrip-
              tion Card (fixed form) that
              defined this area. The
              last two characters are
              blank.

Format	Size	Description
I*4	200 fullwords	The Multispectral Image Storage Tape Identification Record for this area.
R*4	90 fullwords	The Calibration Set Array. This is the same as the array CSET3 from CLACOM. The array is dimensioned three by thirty, providing an element for each possible calibration value for each possible channel. Entries that are not specified by the user are set to the values contained on the Multispectral Image Storage Tape ID record. The elements are ordered such that:

CSET3(1,J) = the value of C0 for
             channel J
CSET3(3,J) = the value of C1 for
             channel J
CSET3(3,J) = the value of C2 for
             channel J
The array is stored on the file row
by column, i.e.,
CSET3(1,1), CSET3(2,1), CSET3(3,1),
CSET3(1,2)...etc.

Record Type 6.   There is one record type 6 for each line in each area
that was classified.   Its length will vary with the number of points
that were classified in the line.   (Represented by pt in the size
column).

Format	Size	Description
I*4	1 fullword	The line number from the Multispectral Image Storage Tape.

Following the line number there is a series of entries, one for
each point in the line.

Format	Size	Description
I*2	(1 x pt) halfwords.	The entry contains two items of data. the First byte of the halfword contains a likelihood code which represents the probability of the point belonging to the class in which it was classified. The larger the code, the greater the probability of correct classification. The code is an integer ranging from 1 to 234. See the CLASSIFYPOINTS algorithm description in the LARSYS User's Manual for information on how the code is calculated. The second byte of the halfword contains an integer identifying the number of the pooled class in which the point was classified.

Record Type 7. At the end of each area that was classified is a single type 7 record to identify the area. It is the same length as the pre-ceeding type 6 record and is distinguished from it by the fact that the line number (first fullword) is set to zero. Only the first fullword of the record is currently used.

Record Type 8. At the end of the results for the last area that was classified in the run (fullowing its type 7 record) is a single type 8 record. This record is the same length as the type 5 record and is distinguished from it by the fact that the "number of points" field (first fullword) is set to zero. Only the first fullword of the record is currently used.
The file is then terminated by a file mark.

(End of LARSYS Manual Items)

The combination program output uses only Type 6,7, and 8 records for carrying the combination information. Furthermore, the first byte of each two byte halfword for each pixel normally contains a likelihood code which is not used in the combination output. Thus, only the line by line (Type 6) results records and the termination records are used. Record types 1 thru 5 are present since the tape cannot be read by LARSYS without them but only information necessary for correct reading of these records is included. No statistics or covariance data

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is included; dummy values are inserted. The pertinent information is carried in the second byte of each halfword in the Type 6 record. The class number, defined on the input cards for the combine program, becomes an integer in this byte.

C. Combination Program

This program consists of a main program (COMBMAIN) and four subroutines which implement the desired functions in FORTRAN IV programming language for an IBM 360 Model 67 type computer. The programs read the input tape and perform combinations as described by input control cards and writes the output in results tape format. The control cards required are listed in the table below. Following the control cards are FORTRAN listings for the various programs. The control card function is indicated by the first word listed. INPUT defines the source MIST merged and grouped tape described above. OUTPUT describes the tape the results format will be written on. The BLOCK card defines a sub area in the MIST tape to be processed. If these cards are missing the program assumes that the existing MIST tape with the Durango East area on it is the input, a scratch tape is assumed as output and the entire area is assumed if the BLOCK card is missing. The only required card type (indicated by *) is the CLASS card. This card is the key input item. It defines the output combinations using the LANDSAT classification results, elevation, slope, and aspect data. The output class is named in the NAME parameter, then the group numbers for the four types of data to be included with that name are listed after NAME. Each output class is defined on a separate card. The end of the input deck is noted by an END card.

An example is included here to aid in understanding the format:

CLASS NAME (SHRUB), ELEV(5-9), VEGE(7-9,16,17,19-22), ASPE(5-9),
SLOPE(1-5)

CLASS NAME(WATER),   VEGE(1)
END

CLASS NUMBER   CLASS NAME
     1   · SHRUB
     2   WATER
     3   -OTHER-

INPUT   TAPE(331), FILE(3)
OUTPUT   TAPE(0), FILE(1)

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This was the input data used to form the big game winter range output. The SHRUB class will consist of LANDSAT vegetation classes 7, 8, 9, 16, 17, 19, 20 21, 22, for elevation groups 5 thru 9, aspect groups 5 thru 9, and slope groups 1 thru 5. The meaning of these groups was defined in Section D6. The first three lines are the input cards printed out. The next six lines are printed by the program to describe the input and assumed parameters. All points not falling into the combination classes are labeled other and given the next highest class number. Tape 331 file 3 is the current location of the Colorado Data and Tape 0 denotes a scratch tape.

CONTROL CARDS FOR COMBINATION CLASSIFIER

Required Format

INPUT TAPE (n_1) [,FILE(n_2)]

        defaults to Colorado tape

OUTPUT TAPE(n_1) [, FILE(n_2)]

        defaults to scratch

BLOCK [LINE (l_1, l_2, l_3),] , [COL(c_1, c_2, c_3)]

        defaults to entire area

* CLASS NAME (clsname)   [, ELEVATION$(list_1)$]

       [, VEGETATION $(list_2)$] [, ASPECT$(list_3)$]

       [, SLOPE$(list_4)$]

Any group(s) may be omitted, indicating a "don't care" situation but relative order of the specified groups must be retained.

If more than one card is needed the data can be split between two or more cards by specifying the same class name on two contiguous class cards.

     (e.g.)   CLASS NAME(A), ELEVATION(1)

             CLASS NAME(A), SLOPE(2)

Lists are of form

n_1, n_2, n_3, or $n_1 - n_2$, $n_3 - n_4$

or any combination thereof

e.g.   (1, 4, 9-12, 15-17, 20)

the numbers represent acceptable variable values for the specified group

*   END

        terminates input to program
        * required cards

```
C
C
C     **** MAIN PROGRAM OF VECTOR CLASSIFICATION SYSTEM              COM00010
C     ****                        DENNIS ADAMS 1976                  COM00020
C                                                                    COM00030
                                                                     COM00040
      IMPLICIT INTEGER (A - Z)                                       COM00050
      COMMON /SPECS/ DUM(4), LINES(3), COL(3), CLS(7, 50),           COM00060
     1 NCLS, STACK(1)                                                COM00070
      INTEGER*4 VECTOR(4,1500)                                       COM00080
      INTEGER*2 LINE(1500)                                           COM00090
      DATA PRINTR/6/, CARDS/5/, TYPE/16/                             COM00100
C                                                                    COM00110
C     **** PRINT HEADING                                             COM00120
C                                                                    COM00130
      WRITE(PRINTR, 10)                                              COM00140
   10 FORMAT('1', 37X, 'LABORATORY FOR APPLICATIONS OF REMOTE SENSING'/ COM00150
     1 51X, 'PURDUE UNIVERSITY' // 51X, 'VECTOR CLASSIFIER'//)       COM00160
C                                                                    COM00170
C     **** READ CONTROL CARDS. LIST CLASSES. LIST TAPES.             COM00180
C                                                                    COM00190
      CALL COMRDR(CARDS, TYPE)                                       COM00200
      WRITE (PRINTR, 20) (I, CLS(1, I), CLS(2, I), I = 1, NCLS)      COM00210
   20 FORMAT(//' CLASS NUMBER   CLASS NAME'//(I10, 6X, 2A4))         COM00220
      K = NCLS + 1                                                   COM00230
      WRITE(PRINTR, 21) K                                            COM00240
   21 FORMAT(I10, 6X, '-OTHER-')                                     COM00250
      WRITE(PRINTR, 25) DUM                                          COM00260
   25 FORMAT(//' INPUT0 TAPE(',I4,'), FILE(',I2,')'/                 COM00270
     1 ' OUTPUT0 TAPE(',I4,'), FILE(',I2,')')                        COM00280
C                                                                    COM00290
C     **** PROCESS DATA.                                             COM00300
C                                                                    COM00310
      CALL RDRTAP(OPEN)                                              COM00320
      NL = (LINES(2) - LINES(1) + 1)/ LINES(3)                       COM00330
      NC = (COL(2) - COL(1) + 1)/COL(3)                              COM00340
      DO 100 I = 1, NL                                               COM00350
      CALL RDRTAP(VECTOR)                                            COM00360
      CALL LOOKUP(VECTOR, LINE, NC)                                  COM00370
      CALL WRTTAP(LINE)                                              COM00380
  100 CONTINUE                                                       COM00390
      STOP                                                           COM00400
      END                                                            COM00410
```

```
      SUBROUTINE RDRTAP(VECTOR)
C
C **** READS DATA POINTS FOR COMBINE SYSTEM.
C
      IMPLICIT INTEGER (A-Z)
      COMMON /SPECS/ ITAPE, IFILE, OTAPE, OFILE, LINE(3), COL(3),
     1 CLS(7,50), NCLS, STACK(1)
      COMMON /IDCOM/ ID(200)
      LOGICAL*1 BUF(8000), PNT(2),ENTER
      INTEGER*2 POINT
      INTEGER*4 VECTOR(4,1)
      DATA ENTER/.FALSE./, INDEV/11/, ERROUT/16/, POINT/0/
      EQUIVALENCE (POINT, PNT)
C
C **** HAS ROUTINE BEEN ENTERED
C
      IF(ENTER) GO TO 1000
      ENTER = .TRUE.
C
C **** MOUNT TAPE, POSITION FILE, CHECK PARAMETERS
C
1     CALL MOUNT(ITAPE, INDEV, #RO#)
      K= IFILE - 1
      IF(K.EQ.0) GO TO 10
      DO 5 I = 1,K
      CALL TOPFF(INDEV)
5     CONTINUE
10    CALL TOPRD(INDEV,800, ERROR, ID)
      IF(ERROR .EQ. 0) GO TO 20
12    WRITE(ERROUT,15) ERROR
15    FORMAT(/#$$$$ READ ERROR #,I3)
      STOP 1
20    IF(ID(1) .NE.ITAPE) GO TO 1
      IF(LINE(1) .NE. 0) GO TO 30
      LINE(1) = 1
```

```
      LINE(2) = ID(20)
      LINE (3) = 1
30    IF(LINE(2) .LE. ID(20)) GO TO 40
      WRITE(ERROUT,35) LINE(2), ID(20)
35    FORMAT(#NUMBER OF LINES#, I5, #TOO LARGE.#,I6, #ASSUMED.#)
      LINE(2) = ID(20)
40    COUNT= LINE(1)
      IF(COL(1) .NE.0) GO TO 45
      COL(1) = 1
      COL(2) = ID(6)-6
      COL(3) = 1
45    K = ID(6) - 6
      IF(COL(2) .LE. K) GO TO 60
      WRITE(ERROUT, 50) COL(2), K
50    FORMAT(#NUMBER OF COLS#, I5, #TOO LARGE.#, I6,#ASSUMED.#)
      COL(2) = K
60    K = K*6
      C1 = COL(1)
      C2 = COL(2)
      C3 = COL(3)
      L = LINE(1) - 1
      IF(L) 90, 90, 70
70    CALL TOPFS(INDEV,L, ERROR)
      IF(ERROR .NE. 0) TO TO 12
90    LENGTH = ID(6) * ID(5) + 4
      RETURN
C
C **** READ DATA RECORD AND FILL VECTOR
C
```

```
1000 CALL TOPRD(INDEV, LENGTH, ERROR, BUF)
     IF(ERROR .EQ. 0) GO TO 1010
     WRITE(ERROUT,I5) ERROR
     STOP 2
1010 M = 1
     DO 1100 I = C1, C2, C3
     DO 1090 J = 1, 4
     PNT(2) = BUF( 4+I + (J-1)*K)
     VECTOR(J,M) = POINT
1090 CONTINUE
     M = M + 1
1100 CONTINUE
     COUNT = COUNT + LINE(3)
     IF(COUNT .LE. LINE(2)) RETURN
     CALL TOPRU(INDEV)
     RETURN
     END
```

```
      SUBROUTINE COMRDR (INPUT, TYPE)                            COM00010
C                                                                COM00020
C **** CONTROL CARD READER FOR COMBINE VECTOR CLASSICATION SYS.  COM00030
C                                                                COM00040
      IMPLICIT INTEGER(A-Z)                                      COM00050
      COMMON /SPECS/ ITAPE, IFILE, OTAPE, OFILE, LINE(3), COLS(3),  COM00060
     1 CLS(7, 50), NCLS, STACK(1)                               COM00070
      LOGICAL*1 CARD(80), OUTSPK,CLSSPK, BLKSPK, BUFL            COM00080
      INTEGER*4 KEYWOR(5), CHN(5), INPAR(4), NAME(2), BUFI       COM00090
      DATA KEYWOR/'INPU','OUTP','BLOC','CLAS','END'/, NKEY/5/,   COM00100
     1 STKPT /1/, INPAR/'TAPE','FILE','LINE','COL'/, CHN/'ELEV','VEGE',  COM00110
     2 'ASPE','SLOP','NAME'/, OUTSPK,CLSSPK,BLKSPK/3*.FALSE./,FILE/1/,  COM00120
     3 BLANK, BUFI/2*' '/                                        COM00130
      EQUIVALENCE (BUFL, BUFI)                                   COM00140
C                                                                COM00150
C **** READ CARD                                                 COM00160
C                                                                COM00170
5     ERROR = 0                                                  COM00180
10    COL  =0                                                    COM00190
      CALL CTLWRD(CARD, COL, KEYWOR, NKEY, KODE, INPUT, ERROR)   COM00200
C                                                                COM00210
C **** EOF  (SAME AS END CARD.)                                  COM00220
C                                                                COM00230
      IF(ERROR .EQ. 2 .OR. KODE .EQ. 5) GO TO 600                COM00240
C                                                                COM00250
C **** 'KILL' TYPED IN  (ABORT JOB.)                             COM00260
C                                                                COM00270
      IF(ERROR .EQ. 4) STOP                                      COM00280
C                                                                COM00290
C **** CONTROL PARAMETERS                                        COM00300
C                                                                COM00310
      IF(COL .EQ. 72) GO TO 105                                  COM00320
C                                                                COM00330
C **** CTLWORD FOUND.                                            COM00340
C                                                                COM00350
      GO TO (100, 100, 300, 400, 600), KODE                     COM00360
C                                                                COM00370
C **** INPUT OR OUTPUT CARD. (READ PARMS.)                       COM00380
C                                                                COM00390
100   CALL CTLPRM(CARD, COL, INPAR, 2, CODE, &105)              COM00400
C                                                                COM00410
C **** PARM FOUND  (PROCESS IT.)                                 COM00420
C                                                                COM00430
      IF(COL .NE .72) GO TO (110, 160), CODE                    COM00440
      GO TO 105                                                  COM00450
C                                                                COM00460
C **** CHECK FOR CUTPUT TAPE AND ASSIGN VALUE.                   COM00470
C                                                                COM00480
```

```
101    IF(KODE .EQ. 2) GO TO 103                                    COM00490
       ITAPE = TAPE                                                 COM00500
       IFILE = FILE                                                 COM00510
       FILE = 1                                                     COM00520
       GO TO 5                                                      COM00530
103    OTAPE = TAPE                                                 COM00540
       OFILE = FILE                                                 COM00550
       FILE = 1                                                     COM00560
       GO TO 5                                                      COM00570
C                                                                   COM00580
C **** ERROR IN CARD. REENTER.                                      COM00590
C                                                                   COM00600
105    ERROR = 1                                                    COM00610
       WRITE(TYPE, 107) CARD                                        COM00620
107    FORMAT(10X,80A1/' ERROR ON CARD. REENTER.',15X,'(COMRDR)')   COM00630
       GO TO 10                                                     COM00640
C                                                                   COM00650
C **** READ TAPE NUMBER                                             COM00660
C                                                                   COM00670
110    K = 1                                                        COM00680
       CALL IVAL(CARD, COL, TAPE, K, &105)                          COM00690
       IF(COL .EQ. 72) GO TO 101                                    COM00700
       GO TO 100                                                    COM00710
C                                                                   COM00720
C **** READ FILE NU,MBER.                                           COM00730
C                                                                   COM00740
160    K = 1                                                        COM00750
       CALL IVAL(CARD, COL, FILE, K, &105)                          COM00760
```

```
      IF(COL .EQ. 72) GO TO 101
      GO TO 100
C
C **** BLOCK CARD. READ PARMS.
C
300   CALL CTLPRM(CARD, COL, INPAR(3), 2, CODE, &105)
C
C **** PARM FOUND  (PROCESS IT.)
C
      IF(COL .NE. 72) GO TO (310, 350), CODE
      GO TO 105
C
C **** READ ILINE, LLINE
C
310   CALL IVAL(CARD, COL, LINE, 3, &105)
      IF(COL .EQ. 72) GO TO 5
      GO TO 300
C
C **** READ ICOL, LCOL
C
350   CALL IVAL(CARD, COL, COLS, 3, &105)
      IF(COL .EQ. 72) GO TO 5
      GO TO 300
C
C **** CLASS CARD. READ PARM.
C
400   CALL CTLPRM(CARD, COL, CHN, 5, CODE, &520)
      IF(COL .EQ. 72) GO TO 520
      IF(CODE .LT. 5) GO TO 510
C
C **** READ NAME
C
      STKTMP = STKPT
      START = COL + 2
      CALL LOCATE(CARD, COL, ')   ', 1, NUM, &105)
      STOP = COL - 1
      CALL LOCATE(CARD, COL, ',   ', 1, NUM, &105)
      COL = COL + 1
      DO 450 I = COL, 72
      BUFI = CARD(I)
      IF(BUFI .NE. BLANK) GO TO 460
450   CONTINUE
      COL = 72
      GO TO 105
460   COL = I - 1
      CALL BCDFIL(CARD, START, STOP, NAME, 8)
      IF(NAME(1) .NE. CLS(1, NCLS) .OR. NAME(2) .NE. CLS(2,NCLS)
     1 ) NCLS = NCLS + 1
      GO TO 400
```

```
COM00770
COM00780
COM00790
COM00800
COM00810
COM00820
COM00830
COM00840
COM00850
COM00860
COM00870
COM00880
COM00890
COM00900
COM00910
COM00920
COM00930
COM00940
COM00950
COM00960
COM00970
COM00980
COM00990
COM01000
COM01010
COM01020
COM01030
COM01040
COM01050
COM01060
COM01070
COM01080
COM01090
COM01100
COM01110
COM01120
COM01130
COM01140
COM01150
COM01160
COM01170
COM01180
COM01190
COM01200
COM01210
COM01220
COM01230
COM01240
COM01250
```

```
C
C **** PROCESS LIST
C
  510   N = 100
        CALL IVAL(CARD, COL, STACK(STKPT), N, &520)
        STKPT = STKPT + N
        CLS(3+CODE, NCLS) = N
        IF(COL .EQ. 72) GO TO 530
        GO TO 400
C
C **** ERROR, CLEAR STKPT
C
  520   DO 521 I = STKTMP, STKPT
        STACK(I) = 0
  521   CONTINUE
        DO 525 I = 4, 7
        CLS(I, NCLS) = 0
  525   CONTINUE
        NCLS = NCLS - 1
        GO TO 105
C
C **** CHECK TO SEE IF CARD WAS EMPTY
C
  530   IF(STKPT .EQ. STKTMP) GO TO 5
        CLS(1,NCLS) = NAME(1)
        CLS(2,NCLS) = NAME(2)
        IF(CLS(3, NCLS) .EQ. 0) CLS(3,NCLS) = STKTMP



        CLSSPK = .TRUE.
        GO TO 5
C
C **** CHECK FOR ALL REQUIRED CARDS.
C
  600   IF(CLSSPK) RETURN
        ERROR = 3
        WRITE(TYPE, 621)
  621   FORMAT(' CLASS CARD(S) REQUIRED',10X,'(COMRDR)')
        GO TO 10
        END
```

```
      SUBROUTINE WRTTAP(LINES)                                      WRT00010
C                                                                   WRT00020
C **** WRITES CLASSIFICATION RESULTS TAPE FOR VECTOR CLASSIFIER     WRT00030
C                                                                   WRT00040
      IMPLICIT INTEGER (A -Z)                                       WRT00050
      COMMON /SPECS/ ITAPE, IFILE, OTAPE, OFILE, LINE(3), COL(3),   WRT00060
     1 CLS(7, 50), NCLS, STACK(1)                                   WRT00070
      COMMON /IDCOM/ ID(200)                                        WRT00080
      INTEGER*4 BUF(3000)                                           WRT00090
      REAL*4 RBUF(3000), PROB(100), DATE(5)                         WRT00100
      INTEGER*2 IBUF(6000), PRBCD, LINES(1), POINT                  WRT00110
      LOGICAL*1 LBUF(12000), ENTER, LPNT(2)                         WRT00120
      EQUIVALENCE (BUF, RBUF), (BUF, IBUF), (BUF, LBUF), (POINT, LPNT) WRT00130
      DATA PROB/100*1./, DATE/5*' '/,PRBCD/ZEA00/, ENTER/.FALSE./,  WRT00140
     1 OUTDEV/12/, EOS/'EOS'/, OTH1, OTH2/'-OTH', 'ER-'/            WRT00150
C                                                                   WRT00160
C **** HAS ROUTINE BEEN ENTERED BEFORE                             WRT00170
C                                                                   WRT00180
      IF(ENTER) GO TO 1000                                          WRT00190
      ENTER = .TRUE.                                                WRT00200
C                                                                   WRT00210
C **** MOUNT OUTPUT TAPE AND POSITION IT.                          WRT00220
C                                                                   WRT00230
      CALL MOUNT (OTAPE, OUTDEV, 'RI')                              WRT00240
      K = OFILE -1                                                  WRT00250
      IF(K) 30, 30, 10                                              WRT00260
 10   DO 20 I = 1, K                                                WRT00270
      CALL TOPFF(OUTDEV)                                            WRT00280
 20   CONTINUE                                                      WRT00290
C                                                                   WRT00300
C **** WRITE RES. REC. TYPE 1.                                     WRT00310
C                                                                   WRT00320
 30   BUF(1) = 1                                                    WRT00330
      BUF(2) = 0                                                    WRT00340
      BUF(3) = OTAPE                                                WRT00350
      BUF(4) = OFILE                                                WRT00360
      BUF(5) = 3                                                    WRT00370
      BUF(6) = 0                                                    WRT00380
      CALL GTSERL(BUF(7))                                           WRT00390
      BUF(8) = 1                                                    WRT00400
      DO 40 I = 9, 14                                               WRT00410
      BUF(I) = 0                                                    WRT00420
 40   CONTINUE                                                      WRT00430
      WRITE(OUTDEV) (BUF(I), I = 1, 14)                             WRT00440
C                                                                   WRT00450
C **** WRITE RES. REC. TYPE 2.                                     WRT00460
C                                                                   WRT00470
```

```
        BUF(1)  =  2                               WRT00480
        BUF(3)  =  NCLS + 1                        WRT00490
        BUF(4)  =  4                               WRT00500
        BUF(5)  =  0                               WRT00510
        BUF(6)  =  BUF(3)                          WRT00520
        DO 50 I  =  1, 4                           WRT00530
        IBUF(12 + I)  =  I                         WRT00540
        IBUF(16+I)  =  1                           WRT00550
        RBUF(10+I)  =0.                            WRT00560
        RBUF(14+I)  =  0.                          WRT00570
50      CONTINUE                                   WRT00580
        DO 60 I  =  1, NCLS                        WRT00590
        BUF(17 + I*2)  =  CLS(1, I)                WRT00600
        BUF(18 + I*2)  =  CLS(2, I)                WRT00610
60      CONTINUE                                   WRT00620
        BUF(19+2*NCLS)  =  OTH1                    WRT00630
        BUF(20+2*NCLS)  =  OTH2                    WRT00640
        N  =  NCLS + 1                             WRT00650
        L  =  40 + 4*NCLS                          WRT00660
        N2  =  2*N                                 WRT00670
        L1  =  L - 1                               WRT00680
        DO 70 I  =  2, N2, 2                       WRT00690
        IBUF(L1 + I)  =  1                         WRT00700
        IBUF(L + I)  =  I/2                        WRT00710
70      CONTINUE                                   WRT00720
        L  =  42 + 6 * NCLS                        WRT00730
        DO 80 I  =  1, N                           WRT00740
        IBUF(L + I)  =  I                          WRT00750
80      CONTINUE.                                  WRT00760
```

```
      CALL GTDATE(DATE)                                               WRT00770
      K = 43 + 7*NCLS                                                 WRT00780
      WRITE(OUTDEV) (IBUF(I), I = 1, K),(PROB(I), I = 1, N), DATE     WRT00790
C                                                                     WRT00800
C **** WRITE RES. REC. TYPE 3.                                       WRT00810
C                                                                     WRT00820
      DO 90 I =1, 22                                                  WRT00830
      BUF(I) = 0                                                      WRT00840
 90   CONTINUE                                                        WRT00850
      K = 4*N + 5                                                     WRT00860
      BUF(1)= 3                                                       WRT00870
      DO 100 I = 1, K                                                 WRT00880
      IF(I .EQ. K) BUF(3) = EOS                                       WRT00890
      WRITE(OUTDEV) (BUF(L) , L= 1, 22)                              WRT00900
 100  CONTINUE                                                        WRT00910
C                                                                     WRT00920
C **** WRITE RES. REC. TYPE 4.                                       WRT00930
C                                                                     WRT00940
      BUF(1) = 4                                                      WRT00950
      K = 14 * N                                                      WRT00960
      IST = 3                                                         WRT00970
      ISTP = 2 + K                                                    WRT00980
      DO 110 I = IST, ISTP                                            WRT00990
      RBUF(I) = 1.                                                    WRT01000
 110  CONTINUE                                                        WRT01010
      WRITE(OUTDEV) (BUF(L), L = 1, ISTP)                            WRT01020
C                                                                     WRT01030
C **** WRITE RES. REC. TYPE 5.                                       WRT01040
C                                                                     WRT01050
      DO 120 K = 6, 311                                               WRT01060
      BUF(K) = 0                                                      WRT01070
 120  CONTINUE                                                        WRT01080
      BUF(1) = 5                                                      WRT01090
      BUF(2) = 1                                                      WRT01100
      BUF(3) = (COL(2) - COL(1) + 1)/COL(3)                          WRT01110
      BUF(4) = (LINE(2) - LINE(1) + 1)/LINE(3)                       WRT01120
      NCOL = BUF (3)                                                  WRT01130
      NLINE = BUF(4)                                                  WRT01140
      BUF(5) = ID(3)                                                  WRT01150
      DO 130 K = 1,3                                                  WRT01160
      BUF(7 + K) = LINE(K)                                            WRT01170
      BUF(10 + K) = COL(K)                                            WRT01180
 130  CONTINUE                                                        WRT01190
      DO 140 K = 22, 221                                              WRT01200
      BUF(K) = ID(K -21)                                              WRT01210
 140  CONTINUE                                                        WRT01220
      WRITE(OUTDEV) (BUF(I), I = 1, 311)                            WRT01230
```

```
C
C **** SET UP RES. REC. TYPE 6. (DATA RECORD)
C
       LENGTH = 6 + NCOL
       BUF(1) = 6
       BUF(2) = 1
       BUF(3) = LINE(1)
       DO 150 K = 7, 6000
       IBUF(K) = PRBCD
 150   CONTINUE
C
C **** WRITE A DATA RECORD
C
1000  DO 1010 I = 1, NCOL
       POINT = LINES(I)
       LBUF(12+2*I) = LPNT(2)
1010  CONTINUE
       WRITE(OUTDEV) (IBUF(I), I = 1, LENGTH)
       BUF(3) = BUF(3) + LINE(3)
       IF(BUF(3) .LE. LINE(2)) RETURN
C
C **** CLOSE FILE AND DISMOUNT TAPE
C
       BUF(1) = 7
       BUF(3) = 0
       WRITE(OUTDEV) (IBUF(I), I = 1, LENGTH)
       BUF(1) = 8
       BUF(2) = 0
       WRITE(OUTDEV) (BUF(I), I = 1, 311)


       CALL TOPEF(OUTDEV)
       BUF(1) = 1
       BUF(3) = OTAPE
       BUF(4) = OFILE + 1
       BUF(5) = 3
       BUF(6) = -1
       WRITE(OUTDEV) (BUF(I), I = 1, 14)
       CALL TOPEF(OUTDEV)
       CALL TOPEF(OUTDEV)
       CALL TOPRU(CUTDEV)
       RETURN
       END
```

```
C      BCDVAL     LARS  0001                                             BCD00010
C                                                                        BCDC0020
C***********************************************************************BCD00030
C                                                                        BCD00040
C  BCDVAL       FINDS AND STORES CHARACTER, INTEGER*4 OR REAL*4          BCD00050
C               VALUES SEPARATED BY COMMAS.                              BCD00060
C               REVISED 10/11/72 BY EARL RODD                            BCD00070
C               REVISED 4/15/76 BY DENNIS ADAMS    TO ACCEPT INTEGER RANGE BCD00080
C                                                                        BCD00090
C***********************************************************************BCD00100
C                                                                        BCD00110
C      SUBROUTINE BCDVAL (CARD,COL,VEC,VECSZ,*)                          BCD00120
C      IMPLICIT INTEGER * 4 (A-Z)                                        BCD00130
C***********************************************************************BCD00140
C                                                                        BCD00150
C   DEFINE PROGRAM VARIABLES                                             BCD00160
C                                                                        BCD00170
C***********************************************************************BCD00180
C      LOGICAL*1 CARD(1), RANGE, NOW, INITI                             BCD00190
C      INTEGER*4 COL,VEC(1),VECSZ                                        BCD00200
C      REAL*4 PNUM,QNUM                                                  BCD00210
C      INTEGER*4 HPOINT                                                  BCD00220
C      INTEGER*4 BLANK,COMMA,PLUS,MINUS,STAR,PERIOD,NUMMIN,MOVE3,HSTAR   BCD00230
C      INTEGER*4 REP,SIGN,VECPOS,VECFIN,WNUM,BUF,INUM                    BCD00240
C      INTEGER*4 SIDE,MORNUM,PCNT,EPOINT,CHAR,HLPRN,LPRN,RPRN            BCD00250
C      LOGICAL*1 BUF1                                                    BCD00260
C      DATA BLANK/' '/,COMMA/','/,PLUS/'+'/,MINUS/'-'/,STAR/'*'/         BCD00270
C      DATA PERIOD/'.'/,NUMMIN/ZF0404040/,MOVE3/Z1000000/,LPRN/'('/      BCD00280
C      DATA RPRN/')'/, RANGE /.FALSE./                                   BCD00290
C      EQUIVALENCE (BUF,BUF1),(QNUM,INUM)                                BCD00300
C***********************************************************************BCD00310
C                                                                        BCD00320
C                       VARIABLES USED IN BCDVAL                         BCD00330
C                                                                        BCD00340
C CARD    = ARRAY CONTAINING CARD TO BE DECODED                         BCD00350
C COL     = POINTS TO LAST COLUMN IN CARD PROCESSED                     BCD00360
C VEC     = ARRAY VALUES ARE STORED IN                                  BCD00370
C VECSZ   = NUMBER OF WORDS IN VEC                                      BCD00380
C BLANK   = CONSTANT     HEX  40404040                                  BCD00390
C PERIOD  = CONSTANT     HEX  4B404040                                  BCD00400
C COMMA   = CONSTANT     HEX  6B404040                                  BCD00410
C NUMMIN  = CONSTANT     HEX  F0404040                                  BCD00420
C PLUS    = CONSTANT     HEX  4E404040                                  BCD00430
C MOVE3   = CONSTANT     HEX  01000000                                  BCD00440
C MINUS   = CONSTANT     HEX  60404040                                  BCD00450
C LPRN    = CONSTANT     HEX  4D404040                                  BCD00460
C RPRN    = CONSTANT     HEX  5D404040                                  BCD00470
```

```
C  STAR    = CONSTANT    HEX 5C404040                                 BCD00480
C  EPOINT  = INDICATES ENTRY POINT                                    BCD00490
C  PNUM    = CONTAINS DECIMAL PART OF NUMBER BEING DECODED            BCD00500
C  WNUM    = CONTAINS INTEGER PART OF NUMBER BEING DECODED            BCD00510
C  SIGN    = CONTAINS SIGN OF NUMBER BEING DECODED                    BCD00520
C  VECFIN  = LAST POSITION IN VEC TO BE FILLED                        BCD00530
C  VECPOS  = NEXT VEC POSITION TO BE USED                             BCD00540
C  CHAR    = CONTAINS LAST CHARACTER PROCESSED                        BCD00550
C  HLPRN   = HAD LEFT PARENTHESIS                                     BCD00560
C  HSTAR   = HAD STAR                                                 BCD00570
        CONTINUE                                                      BCD00580
C  HPOINT  = HAD DECIMAL POINT                                        BCD00590
C  NNUMER  = HAD NON NUMERIC                                          BCD00600
C  PCNT    = NUMBER OF POSITIONS BEHIND DECIMAL POINT                 BCD00610
C  SIDE    = SIDE OF DECIMAL POINT                                    BCD00620
C  MORNUM  = INTEGER DIGIT BEING PROCESSED                            BCD00630
C  BUF     = DUMMY VARIABLE                                           BCD00640
C  BUF1    = FIRST BYTE OF BUF                                        BCD00650
C                                                                     BCD00660
C********************************************************************BCD00670
C********************************************************************BCD00680
C                                                                     BCD00690
C   DECODE VALUES AND STORE IN VEC                                    BCD00700
C                                                                     BCD00710
C********************************************************************BCD00720
C                                                                     BCD00730
C   INITIALIZE ACCORDING TO ENTRY POINT                              BCD00740
C                                                                     BCD00750
      EPOINT=0                                                        BCD00760
```

```
C
C  IF COL COMES IN AS 72, THEN THERE CAN BE NOVALUES        BCD00770
C                                                           BCD00780
                                                            BCD00790
      IF (COL .LT. 72) GO TO 100                            BCD00800
      VECSZ = 0                                             BCD00810
      RETURN                                                BCD00820
      ENTRY IVAL(CARD,COL,VEC,VECSZ,*)                      BCD00830
      EPOINT = 1                                            BCD00840
      GO TO 100                                             BCD00850
      ENTRY FVAL(CARD,COL,VEC,VECSZ,*)                      BCD00860
      EPOINT = 2                                            BCD00870
  100 COL=COL+1                                             BCD00880
      HLPRN=0                                               BCD00890
      VECPOS=1                                              BCD00900
      BUF=BLANK                                             BCD00910
C                                                           BCD00920
C  FOUND IS 0 HERE, IF ANY NON-BLANK IS FOUND, IT IS 1      BCD00930
C                                                           BCD00940
      FOUND = 0                                             BCD00950
C                                                           BCD00960
C  IF COL POINTS TO A COMMA, THEN THERE ARE NO VALUES GIVEN BCD00970
C                                                           BCD00980
      BUF1 = CARD(COL-1)                                    BCD00990
      IF (BUF .NE. COMMA) GO TO 115                         BCD01000
      VECSZ = 0                                             BCD01010
      RETURN                                                BCD01020
  115 K = 1                                                 BCD01030
      BUF1=CARD(COL)                                        BCD01040
      IF(BUF.NE.LPRN) GO TO 110                             BCD01050
      COL=COL+1                                             BCD01060
      HLPRN=1                                               BCD01070
C                                                           BCD01080
C    INITIALIZE                                             BCD01090
C                                                           BCD01100
  110 CHAR=MOVE3                                            BCD01110
      INITI = .TRUE.                                        BCD01120
      BUF=BLANK                                             BCD01130
      NNUMER=0                                              BCD01140
      WNUM=0                                                BCD01150
      PCNT=0                                                BCD01160
      PNUM=0.0                                              BCD01170
      REP=1                                                 BCD01180
      HSTAR=0                                               BCD01190
      SIDE=-1                                               BCD01200
      HPOINT=0                                              BCD01210
      SIGN=+1                                               BCD01220
      IF(RANGE) NCW = .TRUE.                                BCD01230
```

```
C
C   EXAMINE NEXT CHARACTER                                          BCD01240
C                                                                   BCD01250
    120   DO 1159 I=COL,72                                          BCD01260
          BUF1=CARD(I)                                              BCD01270
          IF(CHAR.EQ.MOVE3) CHAR=BUF                                BCD01280
          IF(BUF.EQ.BLANK) GO TO 158                                BCD01290
          FOUND = 1                                                 BCD01300
          IF(BUF.EQ.RPRN) GO TO 156                                 BCD01310
          IF(BUF.EQ.CCMMA) GO TO 157                                BCD01320
C                                                                   BCD01330
C                                                                   BCD01340
C   PROCESS STAR                                                    BCD01350
C                                                                   BCD01360
          IF(BUF.NE.STAR) GO TO 125                                 BCD01370
          IF(HSTAR.EQ.1.AND.EPOINT.GT.0)GO TO 155                   BCD01380
          IF(WNUM.LE.0) GO TO 124                                   BCD01390
          REP = WNUM                                                BCD01400
          CHAR=MOVE3                                                BCD01410
    124   IF(VECPOS+REP-1.GT.VECSZ)GO TO 155                        BCD01420
          NNUMER=0                                                  BCD01430
          WNUM=0                                                    BCD01440
          HSTAR=1                                                   BCD01450
          PCNT=0                                                    BCD01460
          PNUM=0.0                                                  BCD01470
          SIDE=-1                                                   BCD01480
          SIGN=+1                                                   BCD01490
          GO TO 158                                                 BCD01500
    125   IF(BUF.EQ.PLUS)GO TO 158                                  BCD01510
C                                                                   BCD01520




C   PROCESS MINUS                                                   BCD01530
C                                                                   BCD01540
          IF(BUF.NE.MINUS) GO TO 130                                BCD01550
          IF(EPOINT - 1) 126, 127, 126                              BCD01560
    126   SIGN = -1                                                 BCD01570
          GO TO 158                                                 BCD01580
    127   IF(INITI) GO TO 126                                       BCD01590
          TOP = WNUM                                                BCD01600
          RANGE = .TRUE.                                            BCD01610
          GO TO 157                                                 BCD01620
C                                                                   BCD01630
C   PROCESS PERIOD                                                  BCD01640
C                                                                   BCD01650
```

```
      130   IF(BUF.NE.PERIOD)GO TO 140                          BCD01660
            IF(HPOINT.GT.0.AND.EPOINT.EQ.2)GO TO 155            BCD01670
            IF(EPOINT.EQ.1) GO TO 155                           BCD01680
            HPOINT=1                                            BCD01690
            SIDE=+1                                             BCD01700
            GO TO 158                                           BCD01710
      C                                                         BCD01720
      C   PROCESS NUMERIC CHARACTER                             BCD01730
      C                                                         BCD01740
      140   IF(BUF.GE.NUMMIN.AND.BUF.LT.0) GO TO 142            BCD01750
            IF(EPOINT-1) 159,155,155                            BCD01760
      142   MORNUM=(BUF-NUMMIN)/MOVE3                           BCD01770
            NNUMER=1                                            BCD01780
            IF(SIDE.LT.0) GO TO 145                             BCD01790
            PCNT=PCNT+1                                         BCD01800
            PNUM=PNUM+MORNUM*(0.1**PCNT)                        BCD01810
            GO TO 158                                           BCD01820
      145   WNUM=10*WNUM+MORNUM                                 BCD01830
            GO TO 158                                           BCD01840
      C                                                         BCD01850
      C   ERROR--EXECUTE NON STANDARD RETURN                    BCD01860
      C                                                         BCD01870
      155   COL=I                                               BCD01880
            RETURN1                                             BCD01890
      C                                                         BCD01900
      C   PROCESS RIGHT PARENTHESIS                             BCD01910
      C                                                         BCD01920
      156 K=2                                                   BCD01930
            IF(HLPRN.EQ.0) RETURN 1                             BCD01940
      157 COL= I                                                BCD01950
            GO TO 165                                           BCD01960
      C                                                         BCD01970
      C   SET COL AND LOOK AT THE NEXT CHARACTER                BCD01980
      C                                                         BCD01990
      158   COL=I                                               BCD02000
      159   INITI = .FALSE.                                     BCD02010
      1159  CONTINUE                                            BCD02020
      C                                                         BCD02030
      C IF FOUND IS 0, THEN NO NON-BLANKS WERE FOUND            BCD02040
      C (APPLIES ONLY TO ENTRY BCDVAL)                          BCD02050
      C                                                         BCD02060
            IF (FOUND .NE. 0 .OR. EPOINT .GT. 0) GO TO 160      BCD02070
            VECSZ = 0                                           BCD02080
            RETURN                                              BCD02090
      C                                                         BCD02100
      C   END OF CARD                                           BCD02110
      C                                                         BCD02120
      160   IF(HLPRN.GT.0) RETURN 1                             BCD02130
            K=2                                                 BCD02140
      C                                                         BCD02150
      C   PLACE DECODED VALUE(S) IN VEC ARRAY                   BCD02160
      C                                                         BCD02170
```

```
165   IF(NNUMER.EQ.0.AND.EPOINT.GT.0) RETURN 1                    BCD02180
      IF(.NOT.NOW) GO TO 1166                                      BCD02190
      VECFIN = VECPOS + WNUM - TOP - 1                             BCD02200
      KKK = TOP + 1                                                BCD02210
      JJJ = WNUM                                                   BCD02220
      MMM = TOP + 1 - VECPOS                                       BCD02230
      DO 1165 III = KKK, JJJ                                       BCD02240
      VEC(III - MMM) = III                                         BCD02250
1165  CONTINUE                                                     BCD02260
      RANGE = .FALSE.                                              BCD02270
      NOW = .FALSE.                                                BCD02280

      GO TO 1170                                                   BCD02290
1166   VECFIN=VECPOS+REP-1                                         BCD02300
      DO 169 I=VECPOS,VECFIN                                       BCD02310
      IF(EPOINT-1) 166,167,168                                     BCD02320
166   IF(CHAR.EQ.COMMA) CHAR=BLANK                                 BCD02330
       VEC(I)=CHAR                                                 BCD02340
      GO TO 169                                                    BCD02350
167    VEC(I)=SIGN*WNUM                                            BCD02360
      GO TO 169                                                    BCD02370
168    QNUM=SIGN*(WNUM+PNUM)                                       BCD02380
      VEC(I)=INUM                                                  BCD02390
169    CONTINUE                                                    BCD02400
C                                                                  BCD02410
C   LOOK FOR MORE VALUES                                           BCD02420
C                                                                  BCD02430
1170  IF(K.GT.1) GO TO 180                                         BCD02440
      VECPOS=VECFIN+1                                              BCD02450
      IF(VECPOS.GT.VECSZ ) RETURN 1                                BCD02460
      COL=COL+1                                                    BCD02470
      IF(COL.LT.73) GO TO 110                                      BCD02480
      COL=COL-1                                                    BCD02490
      RETURN 1                                                     BCD02500
C                                                                  BCD02510
C   ADVANCE TO NEXT RIGHT PARAMETER AND RETURN                     BCD02520
C                                                                  BCD02530
180    VECSZ=VECFIN                                                BCD02540
      IF(COL.GE.72) RETURN                                         BCD02550
      K=COL+1                                                      BCD02560
      J=0                                                          BCD02570
      L=0                                                          BCD02580
      DO 188 I=K,72                                                BCD02590
      BUF1=CARD(I)                                                 BCD02600
      IF(BUF.NE.BLANK) GO TO 181                                   BCD02610
      J=1                                                          BCD02620
      GO TO 188                                                    BCD02630
```

```
181   IF(BUF.NE.COMMA) GO TO 182                                         BCD02640
      IF(L.GT.0) GO TO 187                                               BCD02650
      L=1                                                               BCD02660
      GO TO 188                                                          BCD02670
182   IF(BUF.EQ.LPRN) GO TO 187                                         BCD02680
183   IF(L.GT.0) RETURN                                                  BCD02690
      IF(J.EQ.0) GO TO 188                                               BCD02700
187   COL=I                                                             BCD02710
      RETURN 1                                                           BCD02720
188   COL=I                                                             BCD02730
      RETURN                                                            BCD02740
      END                                                               BCD02750


C                                                                       COM00010
C     **** COMMON INITIALIZATION FOR VECTOR CLASSIFICATION SYSTEM       COM00020
C                                                                       COM00030
      BLOCK DATA                                                        CCM00040
      IMPLICIT INTEGER (A-Z)                                            COM00050
      COMMON /SPECS/ ITAPE, IFILE, OTAPE, OFILE, LINE(3), COL(3),       COM00060
     1 CLS(7, 50), NCLS, STACK(500)                                     COM00070
      DATA ITAPE, IFILE/331, 3/, OTAPE, OFILE/0, 1/, LINE, COL, NCLS, STCCM00080
     1ACK/507*0/                                                        COM00090
      END                                                               COM00100


      SUBROUTINE LOOKUP(VECTOR, LINE, NC)                               L0000010
C                                                                       LC000020
C     **** GIVEN A FOUR CHANNEL VECTOR LINE THIS FUNCTION RETURNS       LC000030
C     **** THE CLASSIFICATION OF THAT VECTOR LINE AS HALFWORD INTEGERS  L0000040
C                                                                       L0000050
      IMPLICIT INTEGER (A-Z)                                            LC000060
      COMMON /SPECS/ DUMY(10), CLS(7, 50), NCLS, STACK(1)               LC000070
      LOGICAL*1  TABLE(4, 128,50), ENTER                                L0000080
      INTEGER*4 VECTOR(4, 1)                                            L0000090
      INTEGER*2 LINE(1)                                                 LC000100
      DATA TABLE, ENTER/25601*.FALSE./                                  LC000110
```

```
C
C
C    **** HAS ROUTINE BEEN ENTERED
C
      IF(ENTER) GC TO 1000
      ENTER = .TRUE.
C
C    **** SET UP THE VECTOR TABLE.
C
      DO 100 I = 1, NCLS
      T = CLS(3, I)
      DO 50 J = 1, 4
      IF(CLS(3+J, I) .NE. 0) GO TC 30
      DO 20 L = 1, 128
      TABLE(J, L ,I) = .TRUE.
20    CONTINUE
      GO TO 50
30    K = CLS(3 + J, I) + T - 1
      DO 40 L = T, K
      M = STACK(L)
      TABLE(J , M, I) = .TRUE.
40    CONTINUE
      T = K + 1
50     CONTINUE
100    CONTINUE
C
C    **** CLASSIFY A VECTOR.
C
1000  DO 1300 COUNT = 1, NC
      V1 = VECTOR(1, COUNT)
      V2 = VECTOR(2, COUNT)
      V3 = VECTOR(3, COUNT)
      V4 = VECTOR(4, COUNT)
      DO 1100 I = 1, NCLS
      IF(TABLE(1,V1,I).AND.TABLE(2,V2,I).AND.TABLE(3,V3,I)
     1 .AND.TABLE(4,V4,I)) GO TO 1200
1100  CONTINUE
      LINE(COUNT) = NCLS + 1
      GO TO 1300
1200  LINE(COUNT) = I
1300  CONTINUE
      RETURN
      END
```